

CANMET

Canada Centre for
Mineral and Energy
Technology

Centre canadien de la
technologie des
minéraux et de l'énergie

REVIEW OF SELECTED CANMET RESEARCH AND DEVELOPMENT PROJECTS

FINAL REPORT

BY: PEAT MARWICK STEVENSON & KELLOGG



Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada

Canada

THE ENERGY OF OUR RESOURCES - THE POWER OF OUR IDEAS

L'ÉNERGIE DE NOS RESSOURCES - NOTRE FORCE CRÉATRICE



TITLE:

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EXECUTIVE SUMMARY

A. INTRODUCTION

This summary presents our findings and conclusions from our "Review of Selected CANMET Research and Development Projects". We began with an original group of 38 recently completed research and development projects. Fourteen of these were reviewed in detail to identify their social and economic impacts. Nine projects were selected for more detailed probing of their costs and benefits.

Projects were, from:

- Energy Research Laboratories:
 - Fossil fuel heating systems.
 - Safety limits of coking pressure/use of Western Canadian Coals.
- Metals Technology Laboratories:
 - Pressure vessel fabrication technologies.
 - H₂S cracking of line-pipe steels.
- Mining Research Laboratories:
 - Canada-Ontario rockburst project.
 - Diesel exhaust cleaning technology.
- Mineral Sciences Laboratories:
 - Bioleaching of uranium.
 - Supplementary cementing materials.
- Coal Research Laboratories.
 - Monolithic packing technology.

Results are noted in Exhibit 1. As the exhibit illustrates, eight of the projects resulted in a positive net present value. The value of the benefits of these projects exceeded the value of the project costs. The net benefit to society from these eight projects is \$545 million in 1990 dollars. If the results of the ninth project (Pressure Vessel Fabrication Technologies) are included the net benefit to society is \$544 million.

EXHIBIT 1 Findings of Review of Selected CANMET Research and Development Projects

Project	Person-Years	CANMET Costs	Net Present Value (NPV)	Internal Rate of Return (IRR)
	(#)	(million \$)	(million \$)	(%)
Fossil fuel heating systems	66.0	15.1	23.2	NA
Safety limits for coking pressure/use of Western Canadian Coals ¹	9.0	1.6	2.6	25
Pressure vessel fabrication technologies	14.0	4.2	(1.5)	(1)
H ₂ S cracking of line-pipe steels	24.0	4.1	14.5	17
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Monolithic packing technology	<u>1.9</u>	<u>0.3</u>	<u>1.4</u>	25
TOTAL ALL PROJECTS	207.6	43.7	543.7	
TOTAL PROJECTS WITH NPV > 0	193.6	39.5	545.2	

¹Excludes person-years, costs and benefits related to domestic steel makers.

In our opinion, this project would have resulted in a positive net present value except for the:

- Unanticipated decline in the domestic petro-chemical industry.
- Uncompetitiveness of the domestic fabricators in large vessel fabrications.
- Limited use of the technologies in other fabrications.

Two of the projects account for almost 90% of the calculated net present value. This may be a characteristic of research and development activities. Some projects produce benefits exceeding costs while only a few result in substantial net benefits.

As Exhibit 1 illustrates, the nine projects represent the effort of 208 person years of CANMET staff. This is equivalent to 28% of the current staff allocated to CANMET.¹ This person-year expenditure occurred over an average project length of 10.6 years. The shortest project was 4 years in length, the longest included costs over twenty-five years.

Costs of the CANMET projects are \$43.7 million, \$39.5 million if the eight projects with positive net present values are considered. These costs represent 55% (50% excluding Pressure Vessel Fabrication Technologies) of the annual budget for CANMET.

The projects produce benefits exceeding all private and public sector (including CANMET) costs by \$543.7 million (\$545.2 million excluding Pressure Vessel Fabrication Technologies). At current resource levels these project net benefits represent 6.8 years of CANMET activity. Thus, the projects reviewed in our study contribute to society the equivalent of seven years of CANMET operations. Reviewed projects are recent. As a result, most calculated benefits are in the future.

Finally, Exhibit 1 presents the internal rate of return (IRR) for the projects. This rate, which produces a net present value equal to zero, ranges from a low of minus 1% to a high of 104%. This spread of internal rates of return is in keeping with a comprehensive study of 17 innovations in the United States by Manfield *et. al.*² wherein the authors estimate social rates of return ranging from negative values to in excess of 300%.

B. VALIDATION STUDY

Assumptions and findings of the benefit-cost exercise were validated with industry representatives. In general, industry contacts supported the analyses and only minor revisions were made. Exceptions occurred.

For one project (Safety Limits for Coking Pressure/Use of Western Canadian Coals), we have been forced to quantify only one portion of the project -- that benefitting Western Canadian coal producers. In our validation exercise, with domestic steel manufacturers, we were unable to reach agreement on the incremental impact of the project on this group. As a result, we have not quantified benefits or costs for the portion of the project benefitting this group. This project has the potential to add significantly to the benefits calculated for this project.

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¹In this section we use the fiscal year 1990/91 Resource Allocations for CANMET to compare to project findings. We deduct Branches recently added to CANMET (Efficiency & Alternative Energy Technology Branch and Administration of Canada Explosives Act). The CANMET allocations are 732 person years and a budget of \$79.4 million. This budget includes salaries, capital equipment and contract funds. It does not include any allocation for buildings but does include overheads such as the Director General's offices and the Policy, Planning & Services Branch.

²Mansfield, Edwin and John Rapoport, Anthony Romeo, Edmond Villarri, Samuel Wagener, Frank Husic *The Production and Application of New Industrial Technology*, (Norton, New York: 1977).

C. LIMITATIONS OF THE FINDINGS

Our individual project findings over-estimate the net present value of a typical CANMET project. Our findings based on all projects under-estimate the value of CANMET projects to society.

Projects for review were selected based essentially on the size of their expected benefits. As a result, the net present value of the reviewed projects should not be viewed as typical of all CANMET projects. Other projects may offer high benefits. However, not all projects are likely to generate positive net present values. This is the nature of research. In fact, the negative net present value for one project, thought to offer potential benefits, is an example of what can go wrong even with a technically successful project.

We reviewed only nine projects intensively. These projects were found to provide benefits that not only covered the costs of the projects but also produced excess benefits equivalent to seven years of CANMET activities. This calculation does not include the contribution by other CANMET projects. As a result, these are implicitly valued at zero. However, other projects will generate benefits for society. As a result, the figure of seven years is a lower bound estimate of the contribution of CANMET projects.

D. RESEARCH AND DEVELOPMENT POLICY ISSUES

The nine CANMET projects we reviewed levered \$0.97 for every \$1.00 expended by CANMET. Although our sample is small this demonstrated willingness by those outside of CANMET to participate in the funding of the project may provide an a priori measure of the probable economic benefit to be derived from the project.

We found that the reviewed projects also demonstrated a good focus on safety, regional development and environmental concerns.

As a result, we conclude that the projects illustrate contribution toward the listed or implied goals of CANMET's mission statement:

- Leverage of R&D funding : the stimulation of private spending on R&D through public R&D funds.
- Enhancement of health, safety, and environmental controls in client industries.
- Support of the government's goal of balanced regional economic development.

Technology transfer had been successfully achieved for all selected projects. We did not encounter cases where those in targetted industries were unaware of the CANMET project or its results.

SOMMAIRE EXÉCUTIF

A. INTRODUCTION

Ce sommaire présente les résultats et conclusions de notre "Étude de projets choisis de recherche et de développement CANMET."

Les projets provenaient des laboratoires suivants:

- ▶ Laboratoires de recherche sur l'énergie:
 - Systèmes de chauffage à combustible fossile.
 - Limites de sécurité pour la pression de cokéfaction/utilisation du charbon de l'Ouest canadien.
- ▶ Laboratoires de technologie des métaux:
 - Techniques de fabrication des cuves sous pression.
 - Fissuration des aciers de pipelines sous l'influence du H_2S .
- ▶ Laboratoires de recherche minière:
 - Projet sur les secousses rocheuses Canada - Ontario - Industrie.
 - Technique d'épuration du gaz d'échappement provenant des moteurs Diesel.
- ▶ Laboratoires de sciences minérales:
 - Biolixivation de l'uranium.
 - Constituants secondaires du ciment.
- ▶ Laboratoires de recherche sur le charbon:
 - Technique de garnissage monolithique.

Les résultats figurent au Tableau 1. Comme on peut le constater, huit projets présentent une valeur actualisée nette positive, c'est-à-dire que la valeur des avantages qu'ils offrent dépasse celle de leurs coûts. Pour la société, l'avantage net tiré de ces huit projets s'élève à 545 millions de dollars exprimés en dollars de 1990.

TABEAU 1
Résultats de l'étude des projets choisis de recherche et de développement CANMET

Projet	Personne- année	Coûts pour CANMET	Valeur nette actualisée (VNA)	Taux de revenu interne (TRI)
	(No)	(Million \$)	(Million \$)	(%)
Systèmes de chauffage à combustible fossile	66,0	15,1	23,2	N/A
Limites de sécurité pour la pression de cokéfaction/utilisation du charbon de l'Ouest canadien ¹	9,0	1,6	2,6	25
Techniques de fabrication des cuves sous pression	14,0	4,2	(1,5)	(1)
Fissuration des aciers de pipelines sous l'influence du H ₂ S	24,0	4,1	44,5	17
Projet sur les secousses rocheuses Canada - Ontario - Industrie	31,5	4,2	229,0	104
Technique d'épuration du gaz d'échappement provenant des moteurs Diesel	13,8	3,5	22,3	20
Biolixivation de l'uranium	5,4	2,5	6,4	9
Constituants secondaires du ciment	42,0	8,2	245,8	48
Technique de garnissage monolithique	1,9	0,3	1,4	25
TOTAL DE TOUS LES PROJETS	207,6	43,7	543,7	
TOTAL DES PROJETS AYANT UNE VNA > 0	193,6	39,5	545,2	

¹ Les personne-années, les coûts et les bénéfices reliés aux aciéries canadiennes sont exclus.

Si on tient compte des résultats du neuvième projet (techniques de fabrication des cuves sous pression), l'avantage net s'établit à 544 millions de dollars. À notre avis, la valeur nette actualisée de ce projet aurait été positive n'eurent été les éléments suivants:

- ▶ Un ralentissement inattendu dans l'industrie pétrochimique nationale.
- ▶ La non-compétitivité des fabricants canadiens de grosses cuves sous pression.
- ▶ L'utilisation restreinte de la technologie à d'autres fins de fabrication.

Deux des projets représentent presque 90% de la valeur nette actuelle calculée. Ceci est peut-être une caractéristique des activités de recherche et de développement. Certains projets produisent des bénéfices qui sont très peu en excès des coûts, alors qu'une minorité ont pour résultat des bénéfices nets importants.

Tel qu'il est indiqué au Tabelau 1, les neuf projets ont nécessité la participation de 21 personne-années du personnel de CANMET, soit l'équivalent de 28% du personnel actuellement affecté à CANMET.¹ Ces dépenses en personne-années se sont étalées sur une durée moyenne de projet de 10,6 ans. Le projet le plus court a duré 4 ans, le plus long a duré 25 ans.

Les coûts des projets CANMET s'élèvent à 43,7 millions de dollars, et à 39,5 millions de dollars si on ne tient compte que des huit projets qui affichent des valeurs actualisées nettes positives. Ces coûts représentent 55% (50% si on exclut le projet sur les techniques de fabrication des cuves sous pression) du budget annuel de CANMET.

Les projets ont généré des avantages qui dépassent de 543,7 millions de dollars (545,2 millions de dollars si on exclut le projet sur les techniques de fabrication des cuves sous pression) tous les coûts du secteur public et privé. En tenant compte des ressources actuelles, les avantages nets de ces projets représentent 6,8 années d'activité de la part de CANMET. Ainsi, les projets que nous avons étudiés ont contribué à la société l'équivalent de sept années d'activité de CANMET. Les projets étudiés sont récents. Donc, la plupart des avantages calculés seront récoltés dans l'avenir.

¹ À cet égard, nous avons comparé l'affectation de ressources de CANMET pour l'exercice financier 1990-1991 avec les résultats des projets. Nous n'avons pas tenu compte des divisions qui se sont récemment greffées à CANMET (la division Technologie énergétique d'efficacité et de remplacement et Administration de la Loi sur les explosifs Canada). On accorde à CANMET 732 personne-années et un budget de 79,7 millions de dollars. Ce budget comprend les salaires, les biens d'équipement et les fonds destinés à la sous-traitance. Il ne prévoit pas d'allocation pour les bâtiments. Il comprend les frais généraux; par exemple, le bureau du directeur général ou la division des politiques, de la planification et des services.

Enfin, le Tableau 1 montre le taux de revenu interne (TRI) pour les neuf projets choisis. Ce taux, qui produit une valeur actualisée nette de zéro va de moins 1% à 104%. Cet écart entre les TRI minimum et maximum est en accord avec une étude d'ensemble de 17 innovations aux Etats-Unis par Mansfield et al.¹ Dans cette étude, les auteurs ont calculé plusieurs taux de revenu qui s'étalent de valeurs négatives jusqu'à des taux en excès de 300%.

B. ÉTUDE DE VÉRIFICATION

Les suppositions et résultats de l'exercice coût-bénéfice ont été vérifiés avec des représentants de l'industrie. En général, les membres de l'industrie que nous avons contactés supportent l'analyse et seulement des révisions mineures ont été faites. Mais il y a eu des exceptions.

Pour un projet (Limites de sécurité pour la pression de cokéfaction/utilisation du charbon de l'ouest canadien), nous avons dû quantifier seulement une portion du projet -- celle qui a bénéficié les producteurs de charbon de l'ouest canadien. Au cours de notre exercice de validation avec les aciéries domestiques, nous n'avons pas pu arriver à un accord quant à l'effet additionnel net de ce projet sur ce groupe. Donc, nous n'avons pas quantifié les avantages ou coûts pour la portion de ce projet dont avait bénéficié ce groupe. Cet aspect du projet a la possibilité d'augmenter de façon significative les avantages calculés pour ce projet.

Pour un second projet (biolixivation de l'uranium), nous avons réduit les avantages du projet, au cours de notre étape de validation, à la suite de la baisse récente du marché de l'uranium. Cette baisse a eu pour résultat un usage réduit de ce procédé. Nous avons donc réduit nos calculs initiaux de bénéfices (basés sur un marché stable) afin de refléter une conjecture plus récente. C'est l'exercice de vérification qui nous a fourni cette nouvelle conjecture.

C. LIMITES DES RÉSULTATS

D'une part, les conclusions tirées d'un projet particulier surestiment la valeur actualisée nette d'un projet CANMET type. D'autre part, les conclusions tirées de l'ensemble des projets choisis sous-estiment la valeur des projets CANMET pour la collectivité.

Les projets retenus ont été choisis essentiellement d'après l'importance des avantages prévus. Par conséquent, la valeur actualisée nette de chaque projet choisi pour

¹ Mansfield, Edwin and John Rapoport, Anthony Rower, Frank Husic, The Prediction and Application of New Industrial Technology (Norton, New York: 1977).

l'étude ne doit pas être considérée comme l'élément caractéristique de tous les projets CANMET. Il est possible que d'autres projets offrent des avantages importants; toutefois, il est probable qu'ils ne généreront pas tous des valeurs actualisées nettes positives. C'est là la nature même de la recherche. En fait, une valeur actualisée nette négative pour un projet dont on attendait des avantages est un exemple de ce qui peut échouer même si le projet est une réussite au point de vue technique.

Nous n'avons examiné à fond que neuf projets. Nous avons constaté que leurs avantages non seulement couvraient les coûts des projets mais généraient un surplus d'avantages équivalent à sept années d'activités de CANMET. Ce résultat ne tient toutefois pas compte de l'apport des autres projets CANMET. C'est pourquoi, de façon théorique, leur valeur a été établie à zéro. Par ailleurs, d'autres projets généreront des avantages pour la collectivité qui dépasseront les coûts des projets sur le plan social. Ainsi, le résultat de sept ans est une approximation de l'apport minimum des projets CANMET.

D. OBJECTIFS EN MATIERE DE RECHERCHE ET DE DÉVELOPPEMENT

Les neuf projets CANMET que nous avons examinés ont engendré 0.97 \$ de dépenses externes pour chaque dollar dépensé par CANMET. Bien qu'il s'agisse d'un petit échantillonnage, le fait que les sources externes manifestent leur volonté de participer au financement d'un projet nous donne un indice des avantages économiques éventuels qui en découleront.

Nous avons également constaté que les questions touchant l'environnement, le développement régional et la sécurité ont reçu une attention particulière dans le cadre des projets.

Nous concluons donc que les projets s'inscrivent dans l'esprit des objectifs établis ou implicites que CANMET s'est fixés pour remplir sa mission:

- ▶ Levée de capitaux pour financer la recherche et le développement: encourager le secteur privé à consacrer des sommes à la recherche et au développement grâce à des fonds publics destinés à la recherche et au développement.
- ▶ Amélioration de la santé, de la sécurité et des contrôles environnementaux dans les industries clientes.
- ▶ Respect de l'objectif gouvernemental visant à équilibrer le développement économique régional.

Le transfert technologique s'est effectué avec succès pour tous les projets choisis. Nous n'avons rencontré aucun cas où le personnel technique employé par les industries-cibles était sans connaissance du projet CANMET ou de ses résultats.

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I

INTRODUCTION

This report presents our findings and conclusions from our "Review of Selected CANMET Research and Development Projects". We began with an original group of 38 recently completed research and development projects. Fourteen of these were reviewed in detail to identify their social and economic impacts. Nine projects were selected for more detailed probing of their costs and benefits. These impacts were quantified and their value to society estimated.

In this report, we present a benefit-cost analysis of these selected projects. Earlier reports in this project have included:

- Task I -- Screening of Projects.
- Task II -- Methodology Report.

Readers are referred to these documents for a more complete understanding of the methodology used to arrive at the nine selected projects and the benefit-cost approach used in their assessment. We summarize our approach in Chapter III. Chapters IV to VIII present our findings for projects from each of the five main laboratories of CANMET. In Chapter IX we discuss the significance of the projects under review in the context of prevailing R&D policies of the federal government. Our summary and conclusions are presented in Chapter X, while highlights to our report are found in Chapter II.

We have been assisted in this study by the input of staff of two consulting firms Kilborn, and Proctor & Redfern. Analysis and conclusions of the study are solely the responsibility of Peat Marwick Stevenson & Kellogg. We also would like to express thanks to Bernard Faucher, Assistant Program Director, Materials and the other members of CANMET and Alain Barbarie and staff of the Program Evaluation Group of EMR who have given freely of their time for this study.

II HIGHLIGHTS

A. INTRODUCTION

This chapter highlights our findings on the review of selected CANMET Research and Development projects. Further it highlights the significance of the projects in the context of prevailing R&D policies of the Federal government.

B. PROJECT FINDINGS

We reviewed nine CANMET projects in terms of their social costs and benefits. Projects were, from:

- Energy Research Laboratories:
 - Fossil fuel heating systems.
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D. LIMITATIONS OF THE FINDINGS

Our individual project findings over-estimate the net present value of a typical CANMET project. Our findings based on all projects under-estimate the value of CANMET projects to society.

Projects for review were selected based essentially on the size of their expected benefits. As a result, the net present value of the reviewed projects should not be viewed as typical of all CANMET projects. Other projects may offer high benefits. However, not all projects are likely to generate positive net present values. This is the nature of research. In fact, the negative net present value for one project, thought to offer potential benefits, is an example of what can go wrong even with a technically successful project.

We reviewed only nine projects intensively. These projects were found to provide benefits that not only covered the costs of the projects but also produced excess benefits equivalent to seven years of CANMET activities. This calculation does not include the contribution by other CANMET projects. As a result, these are implicitly valued at zero. However, other projects will generate benefits for society. As a result, the figure of seven years is a lower bound estimate of the contribution of CANMET projects.

E. RESEARCH AND DEVELOPMENT POLICY ISSUES

The nine CANMET projects we reviewed levered \$0.97 for every \$1.00 expended by CANMET. Although our sample is small this demonstrated willingness by those outside of CANMET to participate in the funding of the project may provide an a priori measure of the probable benefit to be derived from the project.

We found that the reviewed projects also demonstrated a good focus on safety, regional development and environmental concerns.

As a result, we conclude that the projects illustrate contribution toward the listed or implied goals of CANMET's mission statement:

- Leverage of R&D funding : the stimulation of private spending on R&D through public R&D funds.
- Enhancement of health, safety, and environmental controls in client industries.
- Support of the government's goal of balanced regional economic development.

Technology transfer had been successfully achieved for all projects. We did not encounter cases where those in targetted industries were unaware of the CANMET project or its results.

III APPROACH

A. INTRODUCTION

This chapter presents a brief summary of the methodology used to select and assess research and development projects of CANMET. More detail on these topics may be found in earlier reports:

- Task I -- Screening of Projects.
- Task II -- Methodology Report.

B. SCREENING OF PROJECTS

We reviewed 38 CANMET R&D projects thought to yield potential benefits. From this group we selected 14 projects felt to offer the highest potential benefits. We then screened these projects intensively. Screening included discussions with project officers and other CANMET staff. We used a standardized interview guide which probed for social and economic impacts. Results of the project were reviewed and actual and expected project outcomes were documented. Based on this assessment, and with the aid of the project steering committee, we selected nine projects for further analysis.

The main selection criterion used was the expected size of the benefit of the project to Canadian society. A secondary criterion was that, to cover the five laboratories, we limit our analysis to a maximum of two projects for each CANMET laboratory. A third criterion was the ability to obtain data needed by the benefit-cost study.

Projects selected for the benefit-cost analysis were, from:

- Energy Research Laboratories:
 - Fossil fuel heating systems.
 - Safety limits for coking pressure/use of Western Canadian Coals.
- Metals Technology Laboratories:
 - Pressure vessel fabrication technologies.
 - H₂S cracking of line-pipe steels.
- Mining Research Laboratories:
 - Canada-Ontario rockburst project.
 - Diesel exhaust cleaning technology.

- Mineral Sciences Laboratories:
 - Bioleaching of uranium.
 - Supplementary cementing materials.
- Coal Research Laboratories.
 - Monolithic packing technology.

C. BENEFIT-COST METHODOLOGY

1. Introduction

This section summarizes our general approach to the review of selected CANMET research and development projects. This approach is based on standard benefit-cost methodologies as outlined in such sources as "Guidance for Benefit-Cost Analysis in Evaluations of EMR Energy Programs," Program Evaluation Directorate, Energy Mines, and Resources, January 1987. More detail on this general approach, or our specific approach tailored to each of the selected projects may be found in our Task II report

2. Benefit-Cost Approach

CANMET projects affect the production or consumption possibilities of Canadian society. In our approach we quantify these impacts for each project. Next we value these impacts.

We assess the benefits to society of the selected CANMET projects. Benefits are defined as the gains in production or consumption possibilities for society minus the private sector costs in obtaining goods and services affected by the CANMET activities. (Public sector costs are discussed later.) Benefits are measured in terms of an increase in producer surplus (difference between the selling price and the opportunity cost of production) and an increase in consumer surplus (difference between the maximum willingness to pay and the price the consumer has to pay) for the affected goods and services.

These benefits may occur over a number of years. To assess the magnitude of these benefits more easily (and compare them to costs) we use the social discount rate¹ to adjust benefit streams to a constant base -- 1990 dollars. Thus, we measure the benefits to society as the present value of the annual gains in producer and consumer surpluses which result from CANMET projects.

We compare the present value of benefits to the costs of CANMET activities in two ways:

¹We use a real social discount rate of 7.5% for all projects other than Fossil Fuel Heating Systems. This project, conducted by others and reported by us, uses a 7.0% rate.

- First, we present the approximate costs of the CANMET resources expended to achieve each project's benefit stream. This estimate of costs is based on the person-year costs of the project and the costs of contracted services. We use a value of \$100,000 (in 1990 dollars) per person-year expended¹ on the project and value contracted services at cost. Again the social discount rate is used to adjust the stream of costs to a common base for comparison.
- Our second method assesses the number of years of CANMET activities that could be supported by the social benefits of our selected projects. We first deduct the costs of the selected CANMET projects from our estimate of the benefits of these projects. The remainder represents additional benefits that could be used to justify further CANMET expenditures on research and development.

The method calculates the number of years of CANMET costs, at current rates, that could be incurred to achieve a net present value of zero (present value of remaining benefits equal to the present value of costs). Current CANMET costs, including both person-year and capital costs are used in the analysis. The method calculates the number of years of CANMET costs that are represented by the benefits of the selected projects. In other words it estimates how many years of CANMET research and development could be supported by the selected projects' benefits.

Caution should be exercised in the use of both estimates. The first calculates a net present value for each selected project. However, because projects were selected based on their high expected impacts, we should expect high ratios of benefits to costs. This "cream-skimming" approach means that individual project results should be viewed as representative of what is possible from the "best" CANMET projects but not viewed as what is typical of CANMET projects.

Our second approach calculates the number of years of CANMET activities that could be supported by the benefits of the selected projects. It implicitly assumes that past projects, other than the selected projects, achieve no social benefits. Thus, the method is unduly pessimistic. It underestimates the contribution of CANMET activities to society.

Thus, our two methods present:

- An over-estimate of the average net benefits of individual projects.
- An under-estimate of the total benefits of CANMET research and development activities.

However, given these caveats they remain useful measures of the worth of CANMET research and development projects.

¹This figure includes salary cost and an amount to cover CANMET capital cost.

D. VALIDATION STUDY

We validated our findings for seven projects through survey instruments sent to industry representatives. These instruments presented the assumptions for our cost-benefit analysis and the results of the analyses. Respondents were asked to comment on our assumptions and results. These responses are summarized at the end of sections on each analysis. Where responses resulted in changes to our analysis these are fully discussed in the text.

IV

PROJECTS OF THE ENERGY RESEARCH LABORATORIES

A. INTRODUCTION

This chapter presents the costs and benefits of two projects of the Energy Research Laboratories:

- Fossil fuel heating systems.
- Safety limits for coking pressure/use of Western Canadian coals.

B. FOSSIL FUEL HEATING SYSTEMS

1. Background

The fossil fuel heating program of Energy Research Laboratories was evaluated by Marbek Resources Consultants Ltd. in association with James F. Hickling Ltd.¹ Although the primary objective of the evaluation was not to produce a benefit-cost analysis, the study provides a useful assessment of the project benefits and costs. We have reviewed this work and find its assumptions and conclusions credible. As a result, we report these findings in the following sections.

2. Assumptions of the Model

Basic assumptions of the model are the following:

- Costs are estimated based on person-year resources and external contract values. A value of \$100,000 (in 1987 constant dollars) was used to approximate the opportunity cost of a person-year devoted to the project. The opportunity cost of external contract resources was

¹"Evaluation of CANMET's Fossil Heating Program: Final Report," Marbek Resources Consultants Ltd. and James F. Hickling, August, 1987. Evaluation findings of the study were:

- The program has developed an effective approach to technology development and transfer.
- The program is widely acknowledged to be an excellent model for government involvement in industrial research and development and in product development. The program provides guidance and leadership to all segments of the home heating industry.
- From 1971 to present, substantial efficiency, safety and emission improvements to oil, gas and wood heating appliances have taken place. Today, consumers have a wide choice of improved heating products, and sales data show that these new, more efficient heating appliances are gaining significant market penetration as a result of the cooperative efforts of the program and the home heating industry.
- The program has provided substantial net economic benefits to Canadian consumers, heating equipment manufacturers and other non-manufacturing organizations. The study estimated program costs to date in 1987 present value terms to be \$12.3 million, compared with total quantified nominal benefits of at least \$31.2 million.

valued at the cost of government. Costs were assessed from 1971/72 to 1985/86.

- Benefits to Canadian manufacturers were estimated based on increased export sales. The value to Canada was measured as the before tax profit margin on these units. (Incremental sales were also expected through Canadians buying domestic instead of imported products and switching to fuel efficient units before old heating appliances needed replacement. No benefit was calculated for these additional benefits.)
- Benefits through increased energy efficiency of purchased equipment were calculated as the value of estimated energy savings over the lifetime of equipment. Only incremental domestic sales were used to estimate this benefit. Incrementality was assessed based on interviews with domestic manufacturers. (No benefit was measured for expected increased safety, improved air quality and for increased efficiency as a result of better service of previously installed equipment.)

The analysis assumes that the average saving for the homeowner who installs such equipment is 20 gigajoules (GJ) of secondary energy per year. This value is consistent with an average 20% efficiency improvement for houses using 100 to 110 GJ per year for space heating. Sensitivity analyses were conducted at 15 GJ and 25 GJ. The value of energy savings were calculated using EMR projections of the social opportunity costs of energy products for the residential sector.

From the energy saving was deducted an amount to cover the extra cost of the energy efficient features of the equipment (i.e., the cost of the energy efficient equipment minus the cost of similar equipment but without the energy efficient features). This cost was arbitrarily set at one half the total energy savings in keeping with other recent studies in the area concerning individuals' willingness to pay for energy benefits.

Benefits were estimated based on one year's sales data. A factor of three was used to expand this recent years sales data to the benefits of incremental sales over the period 1971/72 to 1985/86.

- Benefits were estimated to non-manufacturing clients of CANMET (associations, governments and other organizations) based on survey responses. Such clients reported that it would be necessary to create the project if it did not already exist. The cost of such an alternative was assumed to be at least as large as the CANMET costs of the project.

3. Results

The analysis found that the present value of the costs of the fossil fuel heating systems project between 1971/72 and 1985/86 had a present value (in 1987 dollars, using a seven per cent social discount rate) of \$12.3 million. This represents a cost of \$15.1 million in 1990 dollars.

Benefits of the project between the same years, had the following present values, again in 1987 dollars and using a seven per cent social discount rate:

- Benefit to manufacturers -- \$1.16 million.
- Benefit to homeowners -- \$17.80 million.
- Benefit to non-manufacturing clients -- at least \$12.3 million.

Total benefits are therefore estimated to be at least \$31.26 million in 1987 dollars. In terms of 1990 dollars this represents total benefits of \$38.3 million.

Net benefits are therefore estimated to be \$23.2 million in 1990 dollars.

4. Reasonableness of Findings

The study was not intended to represent the definitive statement of the costs and benefits of the project. We have reviewed the assumptions and conclusions of this study and make the following comments. In terms of benefits:

- A number of benefits of the study as noted earlier are not calculated.
- Benefits are only estimated for units sold up until 1985/86. Presumably incremental sales would occur (even if the project were terminated) after this year.
- A factor of three is used to blow up a recent year's sales data to calculate the benefit on sales of units between 1971/72 to 1985/86. Unless it took a lengthy period for research to bear results and for these results to find application in the market place this factor of three appears low.
- Assigning a benefit to export sales based on 20% of the before tax profit assumes that Canadian products are sold at more than their opportunity cost of production in foreign markets. This assumes that Canadian exports have some monopoly power in export markets -- an unusual assumption. However, this potential over-estimate of benefits is of little consequence to the ultimate analysis (\$1.16 million on total benefits of \$31.26 million).

Thus, on balance, benefits appear to be conservatively estimated. Our comments on costs follow:

- Assuming that the costs of energy efficiency features are one-half of the present value of energy savings appears to be arbitrarily high. This implies that the average extra cost paid for the energy efficient feature of incremental domestic units would have been \$789 in 1987 dollars. (\$17,795 million present value of costs + 3 + 7,517 incremental domestic sales [from Figure 4.3 page 4.11].)
- The opportunity cost of a CANMET scientist valued at \$100,000 in 1987 dollars appears appropriate especially if the figure includes the opportunity cost of CANMET overheads and equipment.

On balance, we feel that the costs of research are appropriately valued. However, the cost of the energy efficient equipment is overestimated. This overestimated cost was subtracted from homeowner benefits to arrive at the net benefits to homeowners.

As a result, we conclude, as do the authors of the study, that the analysis is conservative in its estimate of the benefits and net benefits of the research.

C. SAFETY LIMITS FOR COKING PRESSURE/USE OF WESTERN CANADIAN COALS

1. Background

Coke is made from a blend of coals; the majority of the blend is high-volatile coal and 15% to 25% is medium to low-volatile coal. Western Canadian coal is classified as medium-volatile although it varies from low (Smokey River) to high (Fording). To determine if a blend of coals will produce a good coke, a variety of lab- and pilot-scale tests is performed on the coals and on the blend. Historically, the use of Western Canadian coals for coking has been limited by the (unintended) bias of these tests. CANMET has developed more tests which better determine the coking characteristics of Western Canadian coal.

In past, pilot-scale ovens were used to project coking pressures for full-scale coke oven batteries. Tall ovens started to be used in the late 1970s but damage resulted from the inability to properly determine the coking pressures. U.S. Steel ruined a \$125 million (U.S.) battery in 1980. Several tens of millions of dollars were spent repairing damage at Bethlehem Steel's 18 month old coke oven battery. As CANMET developed the tests to characterize Western Canadian coal, they better defined safe coke oven operating pressures. CANMET also developed temperature and pressure sensors to allow better coke oven control. These developments helped extend the life expectancy of coke ovens.

This project, therefore, has two primary outputs:

- It developed tests to better determine the coking characteristics of Western Canadian coal, thereby assisting in the marketing of the product.

- It better defined safe coke oven operating pressures and developed temperature and pressure sensors to allow better coke oven control. These developments helped extent the life expectancy of Canadian coke ovens. Canadian firms use these results and devices to better monitor and control coke oven pressures.

Canada has ten major coking coal producers that may have benefitted from the research: Luscar, Weststar, Denison, Bullmoose, Crowsnest, Esso Resources, Fording, Smokey River, Greg River, and Devco. Devco produces coal with characteristics similar to Appalachian coal (U.S.) which it exports to Europe and South America. The remaining companies sell the majority of their metallurgical coal to Japan, South Korea and Brazil.

In Canada, the only coke oven coal consumers are Algoma, Dofasco and Stelco. Although there are several coke oven coal consumers in the U.S., only two steel producers in the Chicago area have purchased Western Canadian coal.

2. Costs

The costs of the research undertaken by CANMET are estimated in Exhibit IV-1. In the exhibit the opportunity costs of a staff person's time is assumed to be \$100,000 (in 1990 dollars) per year. Other costs are valued based on actual expenditure. Total cost of the CANMET involvement in the program is estimated at \$3.2 million in 1990 dollars.

EXHIBIT IV-1 Present Value of Costs of CANMET Involvement in Safety Limits of Coking Pressure/Use of Western Canadian Coals

Year	CANMET Staff Complement	Annual Staff Cost	Other CANMET Costs	Total Annual Cost	Present Value of Cost
	(PY)	(\$'000)	(\$'000)	(\$'000)	(\$'000)
1981	1	100	160	260	498
1982	4	400	0	400	713
1983	6	600	0	600	995
1984	4	400	0	400	617
1985	2	200	0	200	287
1986	1	100	0	100	134
Total	18				\$3,245

Other costs of the project were borne by other groups. The department of Supply and Services Canada incurred \$160,000 in 1981. Domestic steel makers are estimated to have incurred direct and indirect costs of:

- \$190,000 in 1981.
- \$235,000 in 1982.
- \$250,000 in 1983.

- \$110,000 in 1984.
- \$70,000 in 1985.
- \$50,000 in 1986.

The present value of the costs borne by those other than CANMET is estimated at \$1.8 million.

3. Benefits

This section identifies and calculates the benefits of the project. Benefit impacts result from:

- Use of findings by domestic steel manufacturers.
- Increased saleability of Western Canadian coals.

Each is discussed below.

a) Use of findings by domestic steel producers

All three Canadian steel companies have purchased Western Canadian coal on a trial basis but, for the following reasons, no Canadian steel company continues to use Western Canadian coal currently:

- One company has a problem with trace contaminants in their raw materials. They hope to resolve this problem. Once corrected, Western Canadian coals will be re-evaluated.
- One company uses a rigorous coal specification. They are now re-evaluating these dated specifications and may change the specifications to allow the use of Western Canadian coals.
- One company has found that the rail cost for transport of Western Canadian coals limits the coal's competitive cost.

At least two of the steel companies own coal mines in the Appalachian section of the U.S. which is a further incentive to buy from the U.S.

Although Canadian steel producers have not used the CANMET results to purchase Western Canadian coal they have benefitted from the CANMET results. Canadian coke ovens are old. The last coke oven built in Canada was in 1981. Under ideal conditions the life expectancy of a coke oven should be 25 to 40 years. However, problems determining coking pressures in the U.S. (prior to the CANMET research) suggested that life expectancies might be reduced to 5 to 12 years.

The last coke oven built in Canada cost \$150 million (1981 \$). Additional environmental requirements would increase the cost by approximately 5% to

\$157.5 million (1981 \$). In terms of 1990 dollars, this is equivalent to approximately \$250 million.

In Canada, there are 15 batteries of coke ovens. Given the high replacement cost, any extension in their expected life would bring significant economic benefit. For example, if the CANMET results increase the life of only one battery of coke ovens by ten years (say from 1987 to 1997), the economic value of this deferral is \$1.6 million in 1990 dollars.

Canadian steel makers have used the CANMET findings on safe coke oven operating pressures and adopted the CANMET developed measurement devices.¹ These advances assist coke oven owners operate at safe coke oven pressures and thereby contribute to the longevity of their coke ovens. However, respondents to our validation exercise were unable/unwilling to place a value on the impact of the CANMET results. Comments by respondents include:

- The coke oven failures in the U.S. cannot be used to compare with the Canadian experience due to different operating characteristics of the coals and equipment used.
- There has never been a coke oven failure in Canada.
- Parallel research was being conducted by Canadian steel makers.
- There are too many variables related to a coke oven failure to attribute an impact from an advance in one particular variable to an increase in the longevity of a coke oven.

As a result, we are unable to estimate a benefit to the domestic steel makers that the industry would endorse. Qualitative indications of the benefit of the CANMET work were made however:

- Put coke oven owner in direction of extended life.
- Helped define one restriction they had in their thinking on the problem.
- Allowed them to understand the carbonization process better.

Coke oven owners also benefitted in other ways. One Canadian steel maker noted that the CANMET results had allowed it to change their coking coal blend, increasing the use of a cheaper coal. The steel maker was reluctant to place a value of this cost reduction. As a result, we are unable to quantify this benefit. However, to the extent that Canadian steel producers have been able to reduce costs of their coking blends a benefit results.

¹These devices incorporate both a gas pressure and temperature sensor on a long probe. This probe is inserted into the coke oven to provide accurate readings of coking pressure and temperature.

b) Increased sales of Western Canadian coals

As noted earlier no domestic steel producer uses Western Canadian coals in its coking blends. However, two steel producers in the United States have started purchasing Western Canadian coals after the CANMET project. Annual sales are currently about \$1 million.

Coal producers believe that the CANMET project should be credited with approximately 50% of the increased saleability of the product in the U.S. To estimate the social benefit of the sales increase we take 50% of the contribution to overhead (profit margin estimated from responses) of Canadian coal producers as being the benefit attributable to CANMET. This results in an incremental value of \$30,000 per year (\$5 per tonne profit margin x 12,000 tonnes x 0.5 contribution by CANMET). We limit this benefit to the period 1985 to 1994. The resulting benefit is \$0.2 million in 1990 dollars.

Most sales of Western Canadian coal are to Japan, South Korea and Brazil. Sales to these countries have increased since the CANMET project. Some of this increase may be a result of the CANMET findings especially those related to:

- Reduced coking pressures using Western Canadian coals.
- High hot coke strength using Western Canadian coals.

Domestic coal producers place the contribution of the CANMET results to this sales increase at 1%. Asian steel makers have newer coke ovens that are generally less sensitive to pressure problems. As a result, attribution of the CANMET results to this sales increase is less than for sales to the United States. These assumptions result in an additional benefit of \$250,000 each year (\$5 per tonne profit margin x 5,000,000 tonne sales increase x 0.01 contribution by CANMET). Over twenty years (starting in 1985) the benefit would have a value of \$4.0 million in 1990 dollars.

As a result, we estimate the value of the sales increase of Western Canadian coal at \$4.2 million in 1990 dollars.

4. Summary

Due to uncertainties related to the value of the CANMET research to domestic steel producers, we are unable to quantify the benefit to this sector. The industry has been positively affected, although the magnitude of this impact is conjecture. We therefore implicitly value this benefit at zero.

A quantifiable impact is possible for the domestic coal industry. This impact is estimated to have a value of \$4.2 million in 1990 dollars.

From this attributable benefit should be subtracted the costs to achieve these benefits. The total costs of the research calculated earlier relate to costs incurred to achieve a benefit for:

- Domestic coke oven operators.
- Western coal producers.

Since we have been unable to quantify the benefits related to the first impact, we feel it inappropriate to include the costs related to the research needed to achieve this unquantified benefit. We, therefore, only include the costs to achieve the benefit noted for Western coal producers.

From before, we calculate the benefit to Western coal producers as \$4.2 million. Subtracting the attributable costs of CANMET (\$1.6 million) results in a net benefit to society of \$2.6 million.

Again, we caution that this societal benefit represents the costs and benefits of only one part of the CANMET project. If benefits could be quantified for the remaining portion, the value to Canadian society would most likely increase.

5. Results of Validation

All respondents felt that the CANMET results had been socially worthwhile. However, those in the steel industry were unable to quantify the impact of the research to them. As a result, we have implicitly valued this impact at zero.

Some changes occurred in our estimate of the impact on Western coal sales based on the validation exercise. Changes included a reduction in the longevity of the impact on sales to the U.S. and a reduction in the magnitude of the impact on sales to other countries.

However, these changes had only a minor impact on the value of these benefits to the sector are small in comparison to our inability to quantify an impact for the domestic steel makers.

PROJECTS OF THE METALS TECHNOLOGY LABORATORIES

A. INTRODUCTION

This chapter presents the costs and benefits of two projects of the Metals Technology Laboratories:

- Pressure vessel fabrication technologies
- H₂S cracking of line-pipe steels.

B. PRESSURE VESSEL FABRICATION TECHNOLOGIES

1. Background

CANMET conducted a survey in 1981 which identified narrow gap welding and weld overlay surfacing as the fabrication technologies required by Canadian fabricators to be competitive in the manufacture of large petro-chemical pressure vessels used in the hydrotreatment of heavy oils and in tar sand plants. Such vessels are usually made of high temperature, creep-resistant steel. They can measure up to 100 feet in height, 15 feet in diameter and up to 12 inches in thickness. Up until then, this type of fabrication was sourced off-shore. The traditional method of wide gap welding is not economical for such vessels: narrow gap welding should be used.

CANMET therefore initiated an in-house program with the objective of developing weld procedures for optimizing structure and properties of narrow gap welds and weld overlay surfacing.

Following a standard RFP cycle, a contract was awarded in 1982 to Babcock and Wilcox to act as the CANMET contractor to develop an in-shop capability in narrow gap welding. The work has been completed and is now in the public domain and other fabricators can avail themselves of this knowledge.

In 1985, following an unsolicited proposal from Babcock and Wilcox, CANMET contracted for the development of strip overlay welding techniques. Such techniques are used, for example, to line vessels with a stainless steel surface to provide corrosion resistance. This project therefore has two discrete components: one directed at narrow gap welding; the second at strip overlay welding techniques.

2. Costs

Costs to develop these pressure vessel fabrication technologies are estimated to have a present value of \$4.2 million in 1990 dollars. These costs include annual staff costs, assumed to have a social opportunity cost of \$100,000 per person-year and contract costs at their contracted values. Exhibit V-1 calculates the present value of costs incurred under the project between 1982 and 1989, inclusive.

EXHIBIT V-1 Present Value of Costs of CANMET Involvement in Pressure Fabrication Technologies

Year	CANMET Staff Complement (PY)	Annual Staff Cost (\$'000)	Value of Contracts (\$'000)	Total Annual Cost (\$'000)	Present Value of Cost (\$'000)
1982	2	200	531.1	731.1	1,304
1983	2	200	321.5	521.5	865
1984	2	200	79.3	279.3	431
1985	2	200	73.4	273.4	393
1986	2	200	113.5	313.5	419
1987	2	200	175.3	375.3	466
1988	2	200	0	200.0	231
1989	0	0	56.1	56.1	60
Total	14				\$4,169

3. Benefits

The project was intended to provide domestic fabricators with the technologies needed to be competitive in the market for heavy wall vessels. The petro-chemical industry was seen as the primary market for such vessels. In addition, strip overlay welding techniques may be used to line vessels with a stainless steel surface to provide corrosion resistance. Strip overlay welding techniques will have application in the petro-chemical industry as well as other industries.

However, the expected expansion of the petro-chemical industry did not materialize. After the project was completed the industry entered a contractionary phase. This, coupled with a number of other factors, prevented the domestic fabricators from using the techniques for the petro-chemical industry:

- Domestic fabricators have limited capacity which prevent them from successfully bidding for the large scale fabrications still required by the petro-chemical industry. Fabricators in Canada are limited to a maximum of 700 tonnes. Recent purchases by the petro-chemical industry have exceeded this maximum scale of domestic fabricators. Domestic fabricators are unwilling to invest the resources required to

add to their capacity unless they obtain assurances of winning orders for major vessels.

- Domestic fabricators are at a non-price related disadvantage compared to their foreign counterparts due to the greater familiarity with and proven record of off-shore sources.

As a result, domestic fabricators have not benefitted from the expected sales of pressure vessels to the petro-chemical industry. Given the probable future demand for vessels from this industry, likely capacity of these vessels, and constraints on domestic fabricators, it is unlikely that this industry will have large future sales. The CANMET supported technologies are unlikely to be used by domestic fabricators in support of this industry.

One domestic fabricator has used the technologies in a number of applications in 1984 and 1985. Narrow gap welding and strip overlay techniques were used in the CANMET Heavy Oil Upgrader demonstration plant and six other vessels. These projects had a total value of approximately \$9 million.

Use of the techniques resulted in a saving in the real resource costs of the fabrications over conventional welding techniques. These savings have been estimated at \$0.85 million in 1985 dollars. The present value of this benefit is \$1.2 million in 1990 dollars.

Another fabricator has used the strip overlay techniques in a recent project, to manufacture replacement steam generators, valued at \$35 million. The value of the cladding operation represented about \$300,000 of the total contract amount. However, using other techniques to line the inside of the generator would have cost about \$600,000. The \$300,000 saving, possible through the technique, was not the deciding factor in the award of the contract. (The firm was lowest bidder by a margin of \$6 million). Thus, the saving in real resource costs and not the total value of the contract represents the benefit of the technique for the firm. However, only \$100,000 of this possible saving should be credited to the CANMET project. Ultimately, two-thirds of the work and cladding was sub-contracted to an off-shore fabricator.

The firm expects that future sales of steam generators may result using the strip overlay techniques. Annual cost savings of \$300,000 are expected. These sales are based on a foreign demand for replacement steam generators. We assume that in the short-run these cost-savings will accrue as extra producer's surplus for the domestic producer. In the long-run however, competitive forces will mean that the cost-savings are passed on to the foreign purchaser. Therefore, we assign a declining annual benefit to these expected foreign sales, starting at \$300,000 in 1990 but declining to zero in the year 2000. The present value of this stream of benefits from sales of steam generators using the strip overlay technique is estimated at \$1.5 million. This calculation is presented in Exhibit V-2.

4. Summary

The net present value of the pressure vessels fabrication technologies is calculated as (\$1.5) million in 1990 dollars. This results from costs of \$4.2 million and benefits of \$2.7 million. The net benefits to Canada of the supported technologies would have been larger except for the:

EXHIBIT V-2 Present Value of Benefits from Sales of Steam Generators Using Strip Overlay Technique

Year	Total Resource Savings of Technique (\$'000)	Total Resource Savings for Canada (\$'000)	Present Value of Savings (\$'000)
1988	300	100	116
1989	0	0	0
1990	300	300	300
1991	300	270	251
1992	300	240	208
1993	300	210	169
1994	300	180	135
1995	300	150	104
1996	300	120	78
1997	300	90	54
1998	300	60	34
1999	300	30	16
Total Benefit			\$1.464

- Unanticipated decline in the domestic petro-chemical industry.
- Uncompetitiveness of the domestic fabricators in large vessel fabrications.
- Limited use of the technologies in other fabrications.

With the benefit of hindsight, it may have been more cost-effective for domestic manufacturers to have purchased the technology from abroad. However, given the time period of the study and expectations for that time, the decision to invest in an in-house capability appears reasonable.

C. H₂S CRACKING OF LINE-PIPE STEELS

1. Background

As sweet natural gas wells in Western Canada are depleted, an increasing amount of sour gas is being extracted and pumped through gathering lines. Hydrogen is produced by the corrosion reaction and is absorbed by the steel. This absorption of hydrogen combined with the presence of elongated sulphide inclusions in the steel results in

blisters which lead to weakening and may cause failure of the steel. Failures result in the disruption of pipeline service and potential resulting losses.

All piping in sour service is subject to the effects of sulphide stress cracking (SSC) and step wise cracking (SWC). Sour service piping is that piping which is used to collect natural gas containing more than 1% H₂S from the wells and transport it to a gas processing plant. Here corrosives such as H₂S, and H₂O and others are removed.

As more sour gas is pumped and as wells with higher concentrations of H₂S are accessed, problems are expected to increase. The industry is moving toward the extraction, and pumping through pipelines, of gas of up to 100% H₂S for the production of sulphur. This will create the potential for extreme corrosion problems in the future.

The Energy Resource Conservation Board (ERCB) licences all pipelines within Alberta. (It does not licence interprovincial pipelines.) In 1988, 63% of all pipelines under its responsibility were gas (three per cent are sour gas). The ERCB is responsible for almost 100% of the sour gas pipeline in Canada.

The number of total failures in sour gas service has ranged from a low of seven in 1980 to a high of 30 in 1975. The average between 1975 and 1989 is approximately 20. In 1989 there were 29 total failures in sour gas pipelines. Thirteen of these were because of pipe failure. In 11 cases the failure was attributed to hydrogen induced cracking on small diameter lines. The remaining two cases were related to sulphide stress corrosion cracking and occurred in large diameter pipe. This number of pipe failure, related to H₂S, was judged to be unusually high. A figure of one failure due to H₂S cracking in a lateral and 0.5 in a large diameter pipeline annual was judged to be more typical.

Although the frequency of failures due to H₂S cracking is low, the social cost of such a failure is high.

CANMET activity related to line pipe started in 1971 with a comprehensive program to determine the suitability of commercially available line pipe for service in northern pipelines. The environmental sensitivity of these line pipe steels was recognized during this work and further research into resistance to both external and internal corrosives was carried on.

The CANMET project, Sulphide Stress Cracking of Line-Pipe Steels, had these technical results:

- Determination of critical hydrogen concentration required to cause cracking in a variety of line-pipe steels. The values obtained were used to identify those steels that were very susceptible to cracking (i.e. low critical hydrogen concentration) and others that were much more resistant (i.e. high critical hydrogen concentration).
- C-scan was established as a cost-effective method to determine non-destructively whether cracking has occurred in a sample.

In a parallel effort, Japanese steel mills have developed a low sulphur content steel. Further, they learned to control the shape of the sulphide inclusions. This

method produced a steel line-pipe that was particularly resistant to cracking. Canadian mills were able to adopt this method. Thus, future line-pipe steels will be far more resistant to this problem.

However, the method developed by the Japanese mills does not eliminate all potential problems. As a result of the conclusions reached by CANMET's Sulfide Stress Cracking of Line-Pipe Steels project, C-Scan will be used in the production of line pipe steels to further reduce the probability of a failure in new line-pipe steels.

Research on the effects of H₂S on line-pipe steels has also been conducted by major oil companies and steel manufacturers. As a result, it is difficult to disentangle the portion of benefits that is solely attributable to CANMET. In the following sections we estimate the total impacts that may be attributed to CANMET. In the penultimate section we attempt to present benefits attributable to CANMET.

The research conducted under this project is not applicable to gas pipelines only. The process used to produce heavy water today relies heavily on H₂S. The non-destructive C-scan technique could possibly be used to inspect some steel components in heavy water plants.

2. Costs

Total expenditure on all CANMET work directed at H₂S cracking of line-pipe steels is estimated at \$4.1 million in 1990 dollars. Exhibit V-3 presents data on the annual costs of the project. Research is continuing in the area. At present, the Canadian Petroleum Association through the Canadian Standards Association Sour Service Committee is co-funding CANMET research on a 50/50 basis.

EXHIBIT V-3 Present Value of Costs of CANMET Involvement in H₂S Cracking of Line-Pipe

Year	CANMET Staff Complement (PY)	Annual Staff Cost (\$'000)	Value of Contracts (\$'000)	Total Annual Cost (\$'000)	Present Value of Cost (\$'000)
1979	1.5	150		150	332
1980	2.0	200		200	412
1981	3.0	300		300	575
1982	3.0	300		300	535
1983	3.0	300		300	498
1984	3.0	300		300	463
1985	1.5	150		150	215
1986	1.5	150		150	200
1987	1.5	150	50	200	248
1988	1.5	150	40	190	220
1989	2.5	250	78	328	353
Total	24.0				\$4,052

The private sector will incur costs to achieve benefits noted later. These are the costs of the C-scan instruments expected to be sold over the next two years. The present value of the costs of five units expected to be sold in the next two years is \$1 million in 1990 dollars. (2 units in 1990, 3 units in 1991, each costing approximately \$200,000.)

3. Benefits

The CANMET activities related to H₂S cracking of steel line-pipes are expected to result in the following impacts:

- Reduced accidents in sour gas service in the future.
- Sales of C-Scan equipment that would not otherwise occur.

The benefits of these impacts are discussed below:

a) Fewer Incidents in Sour Gas Service

The CANMET activities will result in fewer accidents in sour gas services in the future. The research will assist manufacturers of steels and line pipes to produce better products that are more resistant to the effects of H₂S.

Based on the data we have analyzed, we conclude that approximately 1.5 failures in sour service line-pipe now occur each year, on average. One of these failures is in a small bore lateral. The remaining 0.5 failures (one every two years on average) is in a trunk line. These failures are expected to grow, in the same ratio of trunk to lateral failures, at 10% annually without the work of CANMET.

This estimate is a conservative one. New sour gas service is currently growing at 10% per annum. (600 kilometers are expected to be added to 6,000 kilometers of existing services.) This rate is expected to increase in the future as sweet gas supplies are depleted. These new services are expected to pump increasing concentrations of H₂S, adding to the potential failure rate.

With the work of CANMET annual failures are expected to remain constant at an average of 1.5 per year. Again this is a conservative estimate. If transmission companies use the CANMET results to refocus their inspection activities on expected problem line pipe this annual rate may be reduced. Such refocussing, if it does occur, is expected no sooner than in 1995. Because of the uncertainty of this benefit we do not include it in our analysis.

The attributable benefit to the CANMET work is the difference between the annual expected failures with and without the CANMET research. This benefit is illustrated by the difference between the annual failures expected with and without the CANMET research in Exhibit V-4.

In Exhibit V-5 we estimate the social costs of a failure in a lateral and in a trunk line. These costs are based on the opportunity costs of the resources needed to repair the failure. They are based on actual costs to repair past failures. They do not include any contingency to cover the value of life or social cost of injury.

EXHIBIT V - 4 Failures in line pipe with and without CANMET research

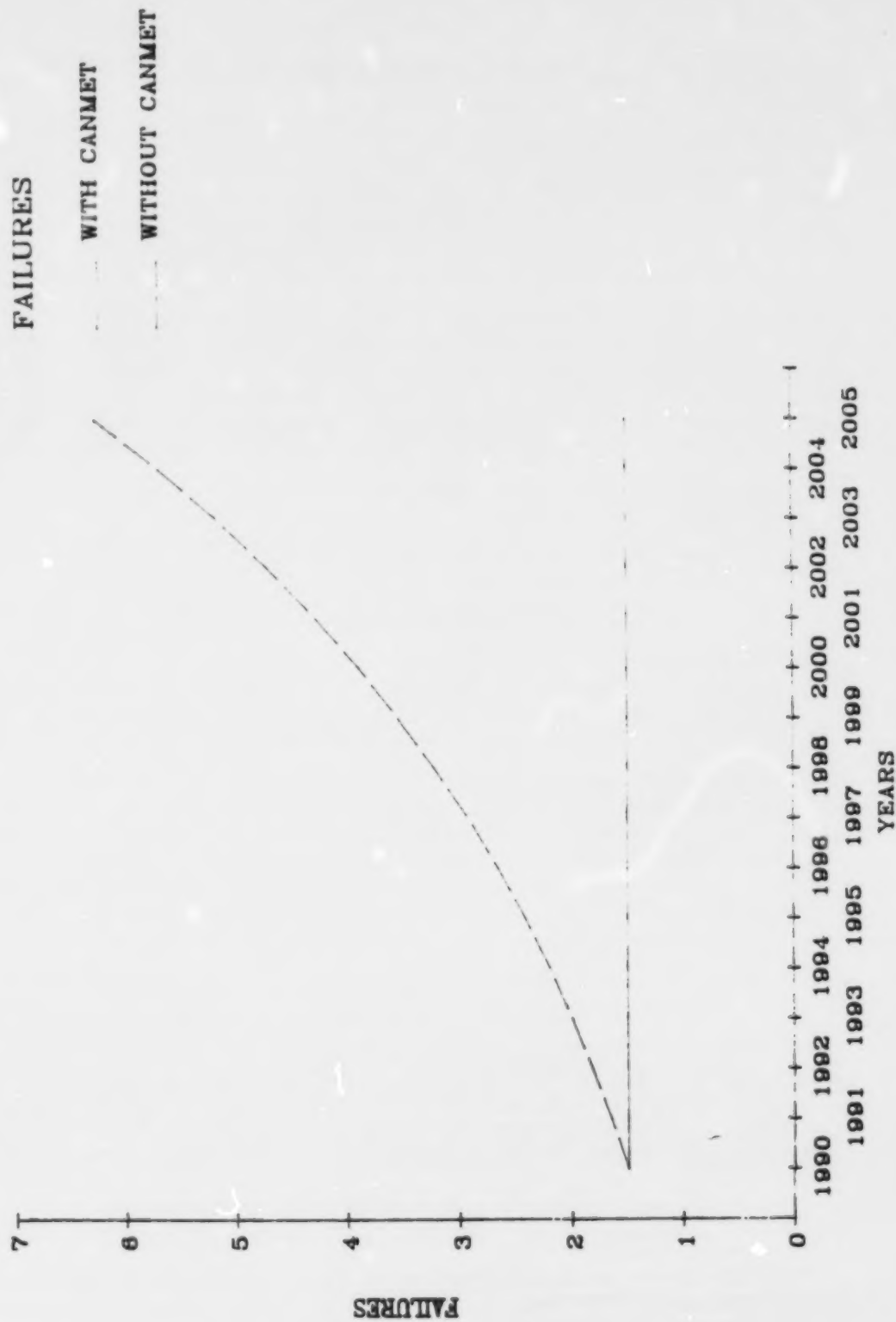


EXHIBIT V-5 Estimated Cost of Failure for Laterals and Trunk Lines

<u>LATERALS</u>	
Assume - Typical flow 5-10 MMCFD - Line length 2-3 miles - Down time 5 days - Replacement local to failure - Alternate source of product 10% premium	
Product lost due to failure 5 MMCF	
- Value of product lost	\$5,000
Deferred Production Revenue $5 \times 10 \text{ MMCFD} \times \$1/\text{MCF} \times .1$	\$10,000
Replacement of line	\$30,000
Cost of Investigation	\$5,000
TOTAL	\$50,000

<u>TRUNK LINES</u>	
Assume - Typical flow 70 MMSCFD - Line length 20 miles - 12 inch diameter line - Replacement cost factor 30,000/diameter inch mile - Full line replacement - Long term investigation - Line out of service 6 months - 12 hours to shut in line - Alternate sources of product 5% premium	
Cost of Lost Product $70,000 \text{ MCFD} \times 1 \times .5$	\$35,000
Deferred Revenue $70,000 \times 1 \times 180 \times .05$	\$630,000
Line Replacement Cost $30,000 \times 12 \times 20$	\$7,200,000
Investigation Cost	\$250,000
TOTAL	\$8,115,000

We did not encounter any examples of injury or death resulting from past failures. However, as concentrations of H₂S rise, the probability of accident involving death or injury rises. In a study¹ of the risk to human life from a proposed sour gas pipeline project, the societal risk² was estimated at one death per 250 years. This risk is a result of all causes, not just those related to failure due to H₂S cracking. Given this low probability of death, we do not estimate a value for risk reduction from the project.

¹Husky Oil -- Caroline Development Project, Volume 10 Risk Assessment, ERCB Application, prepared by Concord Scientific Corporation.

²Risk to the total exposed population.

We also do not consider any social costs to the environment resulting from failures. The ERCB estimates that approximately 70% of all failures (not only those related to H₂S) result in the release of 1 cubic meter of product or less. This small loss and usual remote site of the failure mean that the social value of past damage to the environment has been minimal. This is not to say that future failures will have minimal social costs of environmental damage. We are unable to estimate a value for such damage given the data we have collected. This damage, therefore, has an implicit cost of zero in our estimate. Thus, our estimates of the cost of a lateral failure at \$50,000 and of a trunk failure at \$8.1 million underestimate the likely social cost of such failures.

Exhibit V-6 uses the information of Exhibits V-4 and V-5 to calculate the social benefit as a result of the reduced failures in sour service. The social value of costs avoided by the CANMET activities are estimated to have a present value in 1990 dollars of \$37.9 million. These represent benefits of the CANMET research between the years 1990 and 2005. If a longer time frame were used for the analysis benefits would increase above those noted in Exhibit V-6.

As noted earlier, the private sector will incur costs of \$1 million (purchase price of 5 C-scan instruments) to achieve these benefits. As a result the net benefit to the private sector is estimated a \$36.9 million in 1990 dollars (\$37.9 million benefits minus \$1.0 million costs).

b) Sales of C-Scan Instruments

Canadian manufacturers of C-scan instruments expect a sales increase as a result of the work by CANMET. Sales are expected to the steel industry in the short term and potentially to those specializing in line pipe inspections in the longer term.

As a conservative estimate we assume that two sales of units will result in 1990 and a further three in 1991 directly related to the CANMET research. The average price of these units is \$200,000 and we assume that 10% of this price represents producer surplus. The present value of the gain in producer surplus is \$0.1 million (1990 dollars.)

4. Summary

Costs of the research conducted by CANMET related to H₂S cracking of line-pipe steels are expected to have a social value of \$4.1 million in 1990 dollars.

Total benefits of all research efforts are estimated at \$38.1 million. This represents the present value of avoided costs of failures in sour service line pipe and the surplus on expected incremental sales of C-scan units by domestic manufacturers. The private sector will incur costs of approximately \$1 million to achieve these benefits. As a result, the net benefit to the private sector is estimated at \$37.1 million in 1990 dollars.

Benefits are calculated for the period 1990 to 2005, although benefits will continue in later years. Our estimate of benefits is also underestimated since:

EXHIBIT V-6 Benefit Resulting from Reduced Failures in Sour Gas Service

Year	Failures Without CANMET	Failures With CANMET	Total Reduced Failures	Reduced Lateral Failures	Reduced Trunk Failures	Avoided Cost of Lateral Failures (\$'000,000)	Avoided Cost of Trunk Failures (\$'000,000)	Avoided Cost of All Failures (\$'000,000)	Present Value of Avoided Cost (\$'000,000)
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
1990	1.50	1.50	0.00	0.00	0.00	0.000	0	0	0.000
1991	1.65	1.50	0.15	0.10	0.05	0.005	0.405	0.410	0.381
1992	1.82	1.50	0.31	0.21	0.10	0.010	0.850	0.861	0.745
1993	2.00	1.50	0.50	0.33	0.17	0.017	1.341	1.357	1.092
1994	2.20	1.50	0.70	0.46	0.23	0.023	1.880	1.903	1.425
1995	2.42	1.50	0.92	0.61	0.31	0.031	2.473	2.503	1.744
1996	2.66	1.50	1.16	0.77	0.39	0.039	3.125	3.163	2.050
1997	2.92	1.50	1.42	0.95	0.47	0.047	3.842	3.890	2.345
1998	3.22	1.50	1.72	1.14	0.57	0.057	4.632	4.689	2.629
1999	3.54	1.50	2.04	1.36	0.68	0.068	5.500	5.568	2.904
2000	3.89	1.50	2.39	1.59	0.80	0.080	6.455	6.534	3.170
2001	4.21	1.50	2.78	1.85	0.93	0.093	7.505	7.598	3.429
2002	4.71	1.50	3.21	2.14	1.07	0.107	8.661	8.768	3.681
2003	5.18	1.50	3.68	2.45	1.23	0.123	9.932	10.054	3.927
2004	5.70	1.50	4.20	2.80	1.40	0.140	11.330	11.470	4.167
2005	6.27	1.50	4.77	3.18	1.59	0.159	12.868	13.027	4.403
TOTAL						0.159	12.868	13.027	38.092
						COSTS	AVOIDED		

- Incremental sales only include near term sales.
- The value of environmental damage avoided is not included.
- Benefits noted but not quantified through the validation exercise, such as the value of spin-off research, easier and less costly application process for new sour gas pipelines, and a higher probability of approvals for such pipelines are not included.

Total benefits calculated earlier are likely the result of the combined research efforts of a number of contributors:

- CANMET.
- Canadian Petroleum Association and the CSA Sour Service Committee.
- Oil companies.
- Steel companies.

Respondents in our validation exercise were unwilling to place an estimate on the contribution by any one contributor. However, all felt the contribution by CANMET had been socially worthwhile. CANMET was involved in the research early and was instrumental in heightening awareness, stimulating other researchers, and facilitating the joint research effort. We, therefore, place an attribution of at least 50% to the work of CANMET. This implies that the attributable benefit to CANMET is at least \$18.6 million.

From this figure we subtract the costs of the CANMET resources used by the project (\$4.1 million). Thus, the net present value attributable to CANMET is approximately \$14.5 million.

5. Result of Validation

Costs to repair a lateral failure were adjusted as a result of the validation exercise. This increased the benefit of avoided repair costs, marginally.

The major change as a result of the validation exercise has been to reduce the certainty concerning the amount of total benefits attributable to CANMET. Instead, we attribute the total benefit to the research effort that was facilitated by CANMET and contributed to by CANMET. To estimate the impact attributable to CANMET, we make the somewhat arbitrary assumption of a 50% contribution. Respondents could not estimate a more exact figure.

VI

PROJECTS OF THE MINING RESEARCH LABORATORIES

A. INTRODUCTION

This chapter presents the costs and benefits of two projects of the mining research laboratories:

- Canada-Ontario-Industry Rockburst project.
- Diesel exhaust cleaning technology.

B. CANADA-ONTARIO-INDUSTRY ROCKBURST PROGRAM

1. Background

a) Occurrence of Rockbursts

Rockbursts in Ontario mines have occurred since 1929 or earlier. During the mid 1930s, the number of events seemed to be increasing especially at the Kirkland Lake, Porcupine and Little Long Lac camps. The Ontario Mining Association formed a committee headed by the late Professor R.G.K. Morrison to study the problem. His committee is credited with introducing the concepts of "doming" and "sequential mining" in Ontario. During the next 40 years, the occurrences of rockbursts in Ontario showed a marked decrease due to improved mining conditions (mining practices and ground control measures). Another important factor for the improvement was that low metal prices forced a number of the rockburst-prone mines to close.

There were, however, a few major events during this period of relative tranquility. In 1964, an event in Kirkland Lake resulted in the closure of the Wright Hargreaves Gold Mine. There is also some indication that this event was indirectly responsible for the closure of the adjacent Lake Shore Mine.

During the 1980s, the number of events started to increase dramatically, especially in the Elliot Lake, Sudbury, and Balmertown areas.

There are two main types of rockburst, pillar burst and slippage or fault slip burst:

- The pillar rockburst occurs when either a loading or decrease in strength causes a sudden pillar failure. This release in strain and potential energy usually results in a rapid convergence between the hanging wall and the footwall. This is the most frequent type of rockburst. Because it is the most frequent type of rockburst, it accounts for the most

damage, most injuries and most fatalities. It is the main mechanism at Red Lake, Elliot Lake and Kirkland Lake.

- The fault-slip as the name implies is caused by a slippage along a fault line. This may be mine induced. The slippage type of rockburst is the most dangerous due to the large masses of rock and large changes in energy potential involved. This mechanism is associated with the Sudbury mining basin.

A third type, strain energy burst, is relatively small in nature and does not occur in the magnitude of the others. They take the form of rocks "popping" from the wall as excessive stored energy is dissipated.

Brehaut and Hedley (CANMET 1986), reported that:

"of the 217 rockbursts (of magnitude 1.5 to 4.0 on the Richter Scale) which were recorded in Ontario mines during 1984-1985, 5% were classified as strain energy bursts, 81% as pillar bursts, and 14% as fault-slip bursts."

The most serious events occurring in the 1980's have been in:

- Elliot Lake -- In 1982, as a result of violent pillar failure, a series of rockbursts occurred at the Quirke Mine of Rio Algom Ltd. The next two years were relatively tranquil. From September 1984 to April 1985, over 150 rockburst were recorded in an area of the mine measuring 1,100 m by 600 m. The hanging wall above the ore zone has been fractured to the surface - a distance of 500 m. The mine has since become relatively tranquil again.

The adjacent Denison mine has also experienced seismic activity in the boundary pillar area. They cannot afford to have the hanging wall fracture to surface since the mining operations are directly under the lake. Also a second mine of Denison Mines Ltd. has experienced rockburst problems.

- Balmertown -- In December 1983, the Campbell Red Lake Gold Mine suffered a series of rockbursts in an area of pillars. The damage was substantial, and the mining of the ore zone was suspended.
- Sudbury -- In mid-1984, the two major mining companies in the area, Inco and Falconbridge, experienced major rockburst. In June at the Falconbridge Mine, four miners were killed when the mat above them collapsed as a result of slippage along a major fault. The mine was immediately closed. One month later in the No. 5 shaft area of Inco's Creighton Mine, a similar event occurred. Fortunately, the mine was in a period of vacation shut-down, so no one was

hurt. The damage to the area was severe and the area was closed to further production.

Rockbursting has been a problem at other area mines, notably Inco's North Mine and Falconbridge's Strathcona Mine.

- Other areas -- Although rockbursting is associated mainly in Ontario mines, due to geology and mining methods there have been rockbursts in other parts of the country, primarily Quebec, Saskatchewan and New Brunswick. In July 1989, a major four level event occurred at Brunswick Mining and Smelting's No. 12 mine. The miners refused to work the area.

Mines have been reluctant to place an actual dollar value on the losses attributable to rockburst. Partial information on what is known is presented in Exhibit VI-1.

Exhibit VI-1 Known Losses Resulting from Rockbursts in Ontario

Company	\$ Value	Remarks
Falconbridge	50,000,000	Falconbridge Mine closed because of the fatal rockbursts of June 20, 1984
Inco	?	A producing area of the Creighton Mine closed due to rockburst in July 1984
Campbell Red Lake Mine	20-30,000,000 over 6 years	Mining of a complete ore zone suspended due to December 1983 series of rockbursts
Rio Algom	10,000,000	A series of rockbursts starting in March 1982
Denison	10,000,000	Expected losses due to rockbursts
Wright-Hargreaves Mine	?	Mine closed in 1964 due to the largest rockburst ever recorded (magnitude 5)
Lakeshore Mines	?	Suggested closure was partly due to the above rockburst

? = Unknown value

CANMET staff have estimated losses of \$200 million per annum resulting from rockbursts in existing mines between 1982 and 1984. We have not reviewed the methodology used to derive this estimate.

Data on the annual number of rockbursts and fatalities reported between 1928 and 1987 indicate the peak number of rockbursts occurred at over 300 and deaths at 6 in 1938. Throughout the 1940s and 1950s approximately 75 rockbursts occurred annually and an average of about one death. The early 1960s show a minor peak of events (at around 100). Since that time rockbursts appear stable at about 50 annually.

One death occurred in 1988, four in 1984 and one in 1978. These figures under-estimate the total number of rockbursts, but likely accurately estimate fatalities. The under-reporting results from:

- Miners under-reporting occurrences in abandoned mines or work areas.
- Tendency not to report rockbursts involving less than 5 tonnes of displaced rock if it results in no injuries or fatalities.

Exhibit VI-2 presents data of the recent seismic activity in the Eastern Canada Seismic Network, operated by the Geophysical Division of the Geological Survey of Canada. Incidents record seismic activity of 2.0 or greater.

Exhibit VI-2 Seismic Events of Magnitude 2.0 or Greater in Ontario Mines 1984-1987

Mining District	1984	1985	1986	1987
Red Lake	18	3	6	0
Elliot Lake	46	74	13	8
Sudbury	15	20	35	31
Kirkland Lake	5	2	3	3
Total	84	99	57	42

b) CANMET Developments

Since the start of the rockburst program three types of seismic monitoring equipment have been developed/deployed to record and analyse rockbursts in Ontario mines.

Microseismic systems are used, by the mining companies, to record both small and large seismic events. Source location is obtained in a few seconds and most mines have the capability of automatically plotting the events on digitized mine plans and sections. Most mines with rockburst prone areas would not operate without them. At the beginning of the project there were three microseismic systems in operation and now there are 17 systems.

Macroseismic systems were designed and installed by CANMET to investigate the mechanism and focal parameters of rockbursts. These systems have the capability of recording the seismic waveforms of the larger events (i.e. >1.0 magnitude). By 1990, five macroseismic systems were in operation at the most rockburst prone mines in Ontario.

CANMET has augmented the Eastern Canada Seismic Network operated by the Geological Survey of Canada by installing additional seismograph stations in the mining camps experiencing rockbursts: Sudbury; Elliot Lake; Kirkland Lake; and Red Lake. Magnitudes of the rockbursts are obtained from this network.

Macroseismic monitoring, microseismic monitoring, and computer modelling can all indicate zones prone to pillar type rockburst. These represent 80% of all rockbursts in Ontario. No modelling or monitoring system can recognize fault-slip bursts. The latter is also the situation concerning strain energy bursts, but because of the relatively low level of occurrence, compared to the others, this situation is not considered critical.

Given information on zones prone to pillar type rockbursts mine managers may take appropriate measures to improve the safety of their mine.

Another important result of the developments is that mine managers may pinpoint the location of a rockburst within minutes of its occurrence. Prior to this detection capability, the entire mine would need to be evacuated with each occurrence of a rockburst. Then, teams of miners would need to be sent to all areas within the mine to check for rockburst damage. Potentially, the rockburst would not have occurred within the mine or if it did occur, would have done so in an abandoned or unused portion of the mine. The result would be significant lost production at the mine, not to mention the affect on worker morale.

The microseismic monitoring systems compliment the CANMET macroseismic systems. Both can pinpoint events that take place in a mine, but the CANMET system can also pinpoint events that occur away from the operating area and indicate the size of the event. This information, especially the magnitude of the event, is important to the mine operator as he formulates his response to an event.

With the CANMET development the mine manager is made aware of the location of the rockburst almost instantaneously. If the location is within his mine, he may then remove people from the mine in selected areas only. Within minutes the magnitude of the seismic event is known. Based on this additional information, the mine manager is able to take appropriate steps to determine the extent of problems within the mine. The result is far less disruption of the mine's production. Further, morale of miners is not as adversely affected.

Other achievements of the CANMET project have been:

- Enhancement of industry's knowledge of the causes and mechanisms of rockbursts.
- Focus attention on the use of distress blasting to relieve the potential energy of the surrounding rock mass.
- Progress on the investigation of the types of backfill needed to absorb the surrounding energy, development of numerical models for predictive purposes, and the examination of new or improved support systems.

2. Costs

Costs of the CANMET project are estimated at \$4.2 million in 1990 dollars. These costs are presented in Exhibit VI-3. In addition to costs by CANMET, it is estimated that \$2.5 million of costs were incurred by the Ontario Ministry of Northern Development and Mines and a further \$7.5 million by industry. Assuming that these costs were expended in proportion to CANMET's cost, these additional costs have a present value of \$3.1 million for Ontario and \$9.2 million for industry.

EXHIBIT VI-3 Present Value of Costs of CANMET Involvement in Canada-Ontario Rockburst Project

Year	CANMET Staff Complement (PY)	Annual Staff Cost (\$'000)	Value of Data Collection (\$'000)	Total Annual Cost (\$'000)	Present Value of Cost (\$'000)
1985	3.5	350	55	405	581
1986	7.0	700	55	755	1008
1987	7.0	700	55	755	938
1988	7.0	700	55	755	872
1989	7.0	700	55	755	812
TOTAL	31.5				\$4.212

3. Benefits

a) Benefit through information to estimate the location of a rockburst

A major impact of the project comes as a result of information to estimate the location of the rockburst when an event occurs. This avoids many costs associated with the occurrence of rockbursts in mines.

In Exhibit VI-4 we estimate the annual benefit resulting from better detection. In the exhibit we assume that a mine within a mineral producing region would lose one day's production per seismic event, of magnitude 2.8 or above, without the detection system. With the detection system we assume that the mine would lose one-quarter day's production per seismic event. Benefits are estimated based on the savings in production days and the average value of a day's production. In the case of a seismic event, full production costs are incurred but no production results in the affected period. A reduction in the length of the affected period thus reduces costs (generates a saving). We assume that the cost of a day's production is equal to 90% of the value of output produced in one production day by the affected mine. Based on these assumptions, we estimate an annual saving of \$10.9 million as a result of the better detection.

EXHIBIT VI-4 Annual Saving Through Detection of Seismic Event

Area	Events Per Year	Mines Per Region	Annual Output of Mines Per Region	Days Lost Per Year Before CANMET	Days Lost Per Year After CANMET	Value of Days Lost Before CANMET (6)	Value of Days Lost After CANMET (7)	Savings (8)
	(1)	(2)	(3)	(4)	(5)	(\$'000'000)	(\$'000'000)	(\$'000'000)
Red Lake	3	2	150	1.8	0.45	0.3	0.1	0.2
Elliot Lake	11	4	455	6.6	1.65	1.8	0.5	1.4
Sudbury	33	14	3500	19.8	4.95	12.2	3.0	9.1
Kirkland Lake	3	1	30	1.8	0.45	0.1	0.0	0.1
TOTAL	50	19	4135	30	7.5	14.5	3.6	10.9

NOTES: (1) Annual average seismic events of magnitude 2.0 or above. (For later calculations these are multiplied by 3/5 to estimate the number of seismic events of magnitude 2.8 or above.)

(2) Active mines per region.

(3) Best approximations based on available data.

(4) Column (1) times 3/5. It is assumed that one day's production in a mine is lost for seismic events larger than magnitude 2.8.

(5) Column (4) times 0.25. One-quarter day's production assumed lost in mine on average.

(6) Column (3) times column (4) divided by column (2) times 0.9 divided by 365.25 days per year.

(7) Column (3) times column (5) divided by column (2) times 0.9 divided by 365.25 days per year.

(8) Column (6) minus column (7).

Note that our annual estimate of \$11 million in (1990 dollars) through lost production is less than the annual estimate of \$200 million (\$290 million in 1990 dollars) by CANMET. Our estimate only calculates the value of lost production days that will be affected by the CANMET study. The value of lost ore reserves and other costs unaffected by detection of the seismic event are not estimated in this exhibit.

The value of these savings over twenty years (starting in 1988) has a present value of \$138.0 million. After twenty years the deferred production, due to the seismic events, is assumed to take place. These deferred production days have a value of 10% of the value of output produced in those days (\$24.2 million). This represents the surplus on the production days. Since fewer production days are deferred with the CANMET project this represents a cost to the project. The present value of this cost is \$6.6 million in 1990 dollars. Thus, the net saving through detection of seismic events is estimated at \$131.4 million.

b) Benefit through prediction of areas prone to pillar type rockbursts

The CANMET project has also produced a system capable of predicting, in space, areas prone to pillar type rockbursts. These represent 80% of all rockbursts in Ontario. With such information, preventative measures can be taken in affected mines to reduce the probability of the event (distress blasting) and/or severity of the event (different support systems such as linked wire-mesh/abandon area). It is also likely that better information may reduce injuries and result in fewer mining deaths.

Our validation exercise allowed us to obtain the views of a number of mine experts. We asked them to help estimate the benefit through information on zones prone to pillar type rockbursts.

One such impact of such information is additional production that can be safely mined. We asked respondents if they could estimate this additional production as a percentage increase in the annual output of mines in the four mining regions used by our study. Those who could, placed this percentage increase at from 1% to 3% depending on the respondent and mining region. The highest percentage increases were for the Sudbury Basin.

The likely percentage increase is site-specific, and can range up to 10%. However, we use lower estimates for the overall average by mining area in the following analysis.

Exhibit VI-5 uses these overall averages to estimate the value of the annual increase in production possible through better information on areas prone to pillar rockbursts. It estimates this value by mining region as the annual output of the region (without the information) multiplied by the percentage expected annual production increase multiplied by 10%, to reflect the surplus on this production (see earlier discussion). The exhibit indicates the annual value of the increased production at \$7.6 million. This is the surplus on the additional production that would not have been mined without the information. This annual benefit is calculated over 20 years to yield a present value of \$96.3 million (in 1990 dollars).

We also asked respondents if they could help estimate the likely number of lives that would be saved and injuries avoided over a 10 year period as a result of improved information on zones prone to pillar rockbursts. Estimates for lives saved ranged from zero to 5 in ten years. Injuries avoided ranged from zero to 10.¹

¹One response was rejected since it was substantially higher than other values at 60 lives saved and 120 injuries avoided.

EXHIBIT VI-5 Annual Saving through Information on Zones Prone to Pillar Rock Bursts

Area	Annual Output of Mines Per Region	% Increase in Annual Output	Value of Increase in Annual Output
(1)	(2)	(3)	(4)
	(\$'000'000)	(#)	(\$'000'000)
Red Lake	150	1.0	0.15
Elliot Lake	455	1.0	0.46
Sudbury	3,500	2.0	7.00
Kirkland Lake	<u>30</u>	1.0	<u>0.03</u>
	4,135		7.64

- Notes: (1) Regions with seismic activity.
 (2) Best approximations based on available data.
 (3) Estimates provided through validation exercise.
 (4) Calculated as (2) * (3) * 0.1.

A well established methodology exists (based on the compensation that must be paid a worker in a more risky job) to estimate the value of life saved. No such methodology exists to place a value on an injury avoided. However, this dollar value should increase with the severity of the injury. One respondent noted that injuries resulting from pillar rockbursts tend to be severe. This would indicate that the value assigned to avoiding such an injury should be large.

We have chosen to focus on lives saved to estimate a benefit although we realize that this will underestimate the safety impact of the information. Using a value of two lives saved every 10 years (a median estimate from our validation exercise) and a value of life of \$6 million¹ (in 1990 dollars) produces a present value for this benefit of \$16.7 million over a twenty-year period. We believe this value to be a conservative lower-bound. As a check on this estimate of lives saved we present the following data:

- Deaths attributable to rockbursts in the last 60 years number 58 -- approximately 10 per 10 year period.
- In the 1980's were 5 deaths -- 5 in 10 years.
- Since the rockburst project began in 1985 there have been two deaths -- roughly 4 in 10 years.

¹Based on a \$4.3 million value for life (in 1983 dollars) estimated through labour market data by Douglas Smith and Ronald Meng reported in "Measuring the Benefits of Risk Reduction in Program Evaluation and Regulatory Impact Assessments" *The Canadian Journal of Program Evaluation*, Vol. 4, No. 2, Oct./Nov. 1989. This value is assumed to grow at the real rate of growth of the Canadian economy (1.7%).

As a result, it is conceivable that the better information on pillar rockburst prone areas might reduce fatalities by 2 in 10 years. No comparable statistics are available on injuries due to rockbursts.

Other benefits will result through improved knowledge of areas prone to pillar rockbursts. These include the reduced loss of equipment and costs to rehabilitation areas of the mine where pillar rockbursts have occurred. These benefits are not estimated.

4. Net Benefits

The total benefits of the Canada-Ontario-Industry Rockburst project are estimated at \$245.0 million. From this estimated benefit we subtract the costs of the project incurred by the private sector (\$9.2 million) and Ontario Government (\$3.1 million). Thus, the remaining benefit is estimated at \$233.0 million. Costs to CANMET are estimated at \$4.2 million. The net benefit of the project is therefore calculated to be \$229.0 million in 1990 dollars.

5. Results of Validation Exercise

Our validation exercise allowed us to estimate a benefit for the improved information on areas prone to pillar rockbursts. This was not previously quantified in our analysis but was referred to as a potentially major benefit.

Respondents agreed with our methodology to estimate the benefit of the better detection of the location of rockbursts. A few changes were recommended in the number of mines and annual outputs of mines by region in Exhibit VI-4. The net effect was to increase the value of this calculated benefit.

Most thought the benefits estimated by our analysis would not have occurred without CANMET. The Elliot Lake Laboratory was singled out for the value of its contribution. One respondent thought the benefits might have occurred but they would have taken longer to achieve without CANMET's input.

C. DIESEL EXHAUST CLEANING TECHNOLOGY

1. Background

The Diesel Exhaust Cleaning Technology project produced a ceramic filter that is capable of reducing soot emissions from some diesel engines (those that produce hot exhaust gases). The filter has the following advantages in mining operations:

- Increases the length of time between required major overhaul of underground diesel engines by a factor of two. This reduces maintenance costs, down-time losses, and potentially costs associated with the need for replacement back-ups.
- Reduces soot output of underground diesel engines thereby reducing a potential carcinogenic risk. The soot of diesel engines has been

identified as a probable cancer causing substance. Reduction in the level of soot in the confined space of an underground mine could reduce the cancer risk for workers.

- The filter may have wider application in the future. The United States Environmental Protection Agency and Environment Canada are expected to introduce legislation in 1991 and 1994 respectively to require above ground diesel engines to meet more stringent environmental standards for soot levels. Three methods may be used to help meet the proposed standards:

- Engine redevelopment. Redevelopment will be unable to achieve the entire soot reduction required by the regulation.
- Use of methanol. No infrastructure currently is in place for methanol distribution. As a result, this would be an expensive option and one not available in the near term.
- Filters. Filters appear to be the most cost-effective solution to the soot problem.

CANMET has transferred the technology to the Canadian firm, Engine Control Systems Ltd. It is one of the few firms in the world who have the technology and who will be able to benefit from the expected demand for filters.

2. Costs

Costs by CANMET to develop the technology are estimated at \$3.5 million in 1990 dollars. These costs are based on staff allocated to the project between 1976 and 1989, inclusive. A value of \$100,000 is used to represent the opportunity cost of these person-years. In addition, we allocate the \$533,000 of contracts related to the project in the years 1976 to 1987, at cost, based on the annual person-year complement on the project. (We do not have information on the actual timing of these contracted amounts. The timing of these expenditures is expected to have a minor impact on the total cost of the project.) This cost analysis is presented by Exhibit VI-6.

Costs related to the project but not included in CANMET costs noted earlier are:

➤	Ministry of Labour of Ontario	\$300,000
➤	NRC/PILP	\$300,000
➤	United States Bureau of Mines	\$1,500,000
➤	Equipment manufacturers and mine operators	\$1,000,000

In total, these represent costs of \$3.1 million. Canadians contributed \$1.6 million of this total. Assuming these costs were incurred in proportion to the person year complement of CANMET staff, these total costs have a present value of \$5.6 million. The portion contributed by Canadians has a value of \$2.8 million.

EXHIBIT VI-6 Present Value of Costs of CANMET Involvement

Year	CANMET Staff Complement	Annual Cost of Staff	Annual ¹ Cost of Contracts	Total Costs	Present Value of Costs
	(PY)	(\$'000)	(\$'000)	(\$'000)	(\$'000)
1976	0.2	20	7.8	27.8	77
1977	0.2	20	7.8	27.8	71
1978	0.8	80	31.4	111.4	265
1979	1.0	100	39.2	139.2	308
1980	1.2	120	47.0	167.0	344
1981	2.0	200	78.4	278.4	534
1982	2.0	200	78.4	278.4	496
1983	2.5	250	98.0	348.0	577
1984	2.0	200	78.4	278.4	430
1985	1.0	100	39.2	139.2	200
1986	0.5	50	19.6	69.6	93
1987	0.2	20	7.8	27.8	35
1988	0.1	10	0.0	10.0	12
1989	0.1	10	0.0	10.0	11
Total	13.8		533		\$3,453

¹Contract costs are allocated based on the annual PY's between the years 1976 and 1987, inclusive.

3. Benefits

As noted earlier the project is expected to result in a number of benefits. These are discussed in the following sub-sections and quantified in a later sub-section.

a) Reduced Maintenance Costs of Underground Equipment

In a study conducted at the Brunswick Mining and Smelting No. 12 mine in Bathurst, New Brunswick¹ filters were found to reduce maintenance costs by \$400,000 per year. The costs of filters were included in this net maintenance cost reduction and conservative estimates of the useful life of the filter were used. These reduced maintenance costs relate to the reduced frequency of smoke-related maintenance after filters are installed. Depending on the type of underground diesel equipment, smoke-related maintenance accounts for 4% to 88% of all required maintenance.

As noted earlier maintenance costs reductions include the cost of filters. These were assumed to be \$250,000. A one year life expectancy was assumed for

¹D.L. McKinnon; K.G. Whealand and K. Gavel, "Diesel Particulate Filter Underground Trial at Brunswick Mining and Smelting's No. 12 Mine," SAE Technical Paper Series 891846, September 1989.

these filters, although evidence suggests the expected life is more typically at least two years. As a result, we adjusted maintenance costs for the longer life of the filter and used an expected annual net saving of \$650,000 for the Brunswick mine. The Brunswick mine is atypical due to its strong labour union. Typically diesel equipment is taken out of service if there is excessive smoke. The savings for the Brunswick mine, therefore, overestimate the likely saving for other Canadian mines. A saving of \$100,000 per year would be more typical for the Canadian mine that installs filters on its underground diesel engines.

b) Reduced Carcinogenic Risk

Soot from diesel exhaust has been identified as a possible carcinogen. The risk of lung cancer per person per year of exposure per $\mu\text{g}/\text{m}^3$ (micro gram of particulate per cubic meter) has been estimated by the Environmental Protection Agency¹ at 0.29×10^{-6} to 1.4×10^{-6} . We took the mid-point of the range (0.85×10^{-6}) as our estimate of the annual risk through exposure.

In the Brunswick Mine study the air quality index in the mine was found to improve by a factor of two with the use of the filters. Respirable combustible dust (RCD), which is 75% diesel soot, was found to decrease from $0.49 \text{ mg}/\text{m}^3$ to $0.12 \text{ mg}/\text{m}^3$. This 76% reduction in RCD means that the filters were effective at removing almost 100% of the soot from the underground environment. The remaining $0.12 \text{ mg}/\text{m}^3$ (25% of 0.49) was mostly drill oil mist and engine and/or hydraulic oil burning off the engine. We use the efficiency factor found in the laboratory (90%) as a more conservative estimate of the soot reduction. Using these values we estimate the probability of cancer per mine worker with and without filters. Mine-related exposure is assumed to be eight hours for each working day (225 per year). Therefore, the miner is assumed to be exposed to the elevated soot levels of the mine 21% of the year ($8 \text{ hrs} + 24 \text{ hrs/day} \times 225 \text{ days} + 365.25 \text{ days/year}$). We assume a 30 year average working life for a miner. As a result, the probability of lung cancer from mine related soot exposure would be 2.0×10^{-3} without filters and 2.0×10^{-4} with filters.² Therefore, the filters reduce the probability of contracting lung cancer from soot inhalation related to a lifetime of mine exposure from 2.0 per 1000 workers to 0.2 per 1000 workers. The five year survival rate for lung cancers is 8% for males.³ Thus, we may assume that these cancer incidents translate into deaths due to cancer.

Therefore 1.8 workers per 1000 are expected not to get lung cancer and consequently not die after working for 30 years in a mine where filters are installed. On an annual exposure basis the risk is reduced by 6.0×10^{-5} from 6.6×10^{-5} to 6.6×10^{-6} .

¹Penny M. Carey, "Air Toxics Emissions from Motor Vehicles: Technical Report ESA -AA- TSS -PA - 86 - 5." U.S. Environmental Protection Agency, September 1987.

²Probabilities are calculated as follows:

Without filters:

$$0.85 \times 10^{-6} (\text{annual risk at } 1\mu\text{g}/\text{m}^3) \times 0.49 \text{ mg}/\text{m}^3 \times 0.75 (\% \text{ of RCD that is soot}) \times 1000 \times 30 \text{ years} \times 0.21$$

With filters:

$$0.85 \times 10^{-6} \times 0.49 \text{ mg}/\text{m}^3 \times 0.75 \times .1 (\text{assumed remaining soot base on laboratory findings}) \times 1000 \times 30 \text{ years} \times 0.21$$

³Canadian Cancer Society, Canadian Cancer Statistics 1988.

c) Cost Savings to Meet Expected Environmental Regulations

Canada and the United States are expected to introduce regulations to limit the allowable diesel soot exhaust from new transit buses and new trucks. In the U.S. the regulation is expected to reduce allowable soot to the following levels:

- 0.1 gm/BHP output for new buses in 1991.
- 0.25 gm/BHP output for new trucks in 1991.
- 0.1 gm/BHP output for new trucks in 1994.

The Canadian government is expected to introduce regulations on all new trucks and buses at 0.1 gm/BHP output in 1994.

It is expected that engine manufacturers can meet 0.25 gm/BHP by engine modifications alone. The main thrust of development work is to use engine modifications in conjunction with filters. The CANMET supported filter design is only one of the current filter technologies that may be used. Others include:

- Ceramic foam.
- Fibre.
- Metallic mesh.
- Sintered ceramic disk.

The CANMET filter technology is the most expensive.

Other technologies using alternate fuels are possible. These include methanol and propane. However, the conversion costs for methanol are expected to be \$25,000 (U.S. \$) per vehicle. The cost to operate a methanol bus is approximately six times that of diesel. Further, there are additional costs of approximately \$1 million per fueling station and increased risk of accident in urban settings. Propane conversion would be \$16,000 (U.S. \$) per vehicle while the costs using filters are estimated at \$8,000 (U.S. \$).

The filter technology appears to be the cheapest available method to meet the impending regulations at least in the foreseeable future. A benefit will result equal to the difference between the cost of the filter technology and next cheapest technology available on each unit produced using the CANMET results.

d) Sales Impact

The Canadian manufacturer of the CANMET supported technology expects to capture a portion of the expected future demand for filters in below ground and above ground applications. A benefit will result to the extent that the selling price on such units exceeds the opportunity costs of the resources used to produce these units. We use a

maximum 10% margin to conservatively estimate such an impact. This margin declines over time until the margin is zero at which time selling price and opportunity cost are equal.

To estimate the number of units sold by the firm we use a combination of past sales experience and expected volumes for the firm. By year, the sales of units is expected to have a dollar value of:

- 1988 -- 0.75 million.
- 1989 -- 1.1 million.
- 1990 -- 1.5 million.
- 1991 -- 6.5 million.¹
- 1992 -- 6.5 million.
- 1993 -- 6.5 million.
- 1994 -- 12.0 million.²
- 1995 -- 12.0 million.

Our sales impacts include a small number of sales of units for Canadian mines. If the filters were regulated in all mines using below ground diesel equipment, approximately 20 mines would be required to install filters. However, we assume that only the current number of mines in Canada already using the filters will continue to use filters without legislation. To date, only the Brunswick mine has installed filters on most production and some haulage equipment and in two other mines (Inco and Falconbridge), filters have been installed in problem areas only.

Other countries are potential buyers of the Canadian filters for below ground applications:

- Currently Western Australia takes most of the world's output of filters.
- South Africa wants to implement the use of filters.
- The U.S. is testing systems in six mines. In the U.S. regulations govern the amount of pollutants in the air of the mine.
- Japan, Borneo and New Guinea are potential markets.

Other sales are expected for mechanical handling in warehouse applications.

¹Estimates for 1991 to 1993 assume that the U.S. regulation is introduced, 20,000 new buses annually require the filters, the filters cost \$2,500 and the Canadian firm captures one-tenth of the market.

²Estimates for 1994 and beyond assume the Canadian regulation is introduced and the U.S. regulation also is lowered to require new trucks to use filters.

e) **Quantification of Benefits**

As noted earlier, benefits result from:

- Reduced maintenance costs of underground equipment.
- Reduced carcinogenic risk.
- Cost savings to meet expected environmental regulations.
- Sales impacts.

These are quantified in this section.

Exhibit VI-7 calculates the expected saving in reduced maintenance costs of equipment used in mines installing filters. The exhibit assumes that six mines in Canada install filters. One mine, the Brunswick mine, installs filters on most equipment and saves \$650,000 per year. (Recall that this figure is abnormally high due to the particular circumstances of the mine.) The other five mines install filters in problem areas only and achieve an annual net saving of \$100,000 for each such mine. Further, we assume a useful remaining life of 15 years for each mine. (Additional mines may adopt the filter technology should regulations be introduced regarding the soot levels allowable in the mine environment. We do not calculate a benefit assuming regulations are enacted.)

EXHIBIT VI-7 Benefit Through Reduced Maintenance Costs of Underground Equipment

Year	Annual Saving Installation in Brunswick Mine (\$'000)	Annual Saving for Installation in Other Mines (\$'000)	Total Annual Saving (\$'000)	Present Value of Savings (\$'000)
1988	650	500	1,150	1,329
1989	650	500	1,150	1,236
1990	650	500	1,150	1,150
1991	650	500	1,150	1,070
1992	650	500	1,150	995
1993	650	500	1,150	926
1994	650	500	1,150	861
1995	650	500	1,150	801
1996	650	500	1,150	745
1997	650	500	1,150	693
1998	650	500	1,150	645
1999	650	500	1,150	600
2000	650	500	1,150	558
2001	650	500	1,150	519
2002	650	500	1,150	483
Total Benefit				\$12,611

Based on these assumptions, the present value of reduced maintenance costs in underground applications in Canada is \$12.6 million (in 1990 dollars).

The effect of the reduced carcinogenic risk is noted in Exhibit VI-8. In this exhibit we assume that the mines, which install filters, employ a total of 900 miners in areas where filters are installed. Miners retire after 30 years of work and are replaced by first-time workers. This occurs at a constant rate of 30 workers each year. The exhibit calculates the reduced risk of cancer for miners as they retire (to the year 2002) based on the reduced soot levels for each year worked since the filters are installed. It also calculates an average exposure for the 900 miners who are assumed to be laid off in the year 2003 when the 15 year life of the mines is over. This average exposure at the reduced rate would be 7.5 years for these miners.

EXHIBIT VI-8 Benefit Through Reduced Carcinogenic Risk to Mine Workers

Year	Years of Exposure at Reduced Level	Miners Subject to Reduced Exposure	Reduced Risk	Reduced Incidence of Cancer	Value of Life (\$'000)	Annual Value of Lives Saved (\$'000)	Present Value of Savings (\$'000)
1988	1	30	6.0E-05	0.002	5,801	10	12
1989	2	30	6.0E-05	0.004	5,900	21	23
1990	3	30	6.0E-05	0.005	5,600	32	32
1991	4	30	6.0E-05	0.007	6,102	44	41
1992	5	30	6.0E-05	0.009	6,206	56	48
1993	6	30	6.0E-05	0.011	6,311	68	55
1994	7	30	6.0E-05	0.013	6,419	81	61
1995	8	30	6.0E-05	0.014	6,528	94	65
1996	9	30	6.0E-05	0.016	6,639	108	70
1997	10	30	6.0E-05	0.018	6,751	122	73
1998	11	30	6.0E-05	0.020	6,866	136	76
1999	12	30	6.0E-05	0.022	6,983	151	79
2000	13	30	6.0E-05	0.023	7,102	166	81
2001	14	30	6.0E-05	0.025	7,222	182	82
2002	15	30	6.0E-05	0.027	7,345	198	83
2003	7.5	900	6.0E-05	0.405	7,470	3,025	1,182
						Total Benefit	\$2,063

Assuming a reduced risk of 6.0×10^{-5} (as calculated earlier) and a value of life of \$6 million,¹ in 1990 dollars, the value of the reduced carcinogenic risk to exposed miners is \$2.1 million in 1990 dollars.

¹See earlier discussion on the appropriate value of life. This value of life is assumed to grow at the real rate of growth of the economy, or at 1.7 per annum.

The information generated as a result of this technology may reduce the risk of cancer for more miners than those identified in our analysis. Based on this information, Ontario will draft better regulations regarding the use of diesel engines underground. To the extent that this regulatory change will reduce the levels of soot in mines, benefits through reduced risk of cancer should be increased. We do not estimate a benefit through this effect.

Cost savings to meet expected environmental regulations are estimated in Exhibit VI-9. Here we assume the Government of Canada introduces such legislation in 1994. It affects 2,000 new buses annually and 4,000 new trucks in Canada. We assume a \$9,400 cost differences in 1990, (\$8,000 U.S.) between the annual cost of filters and the next best alternative available, propane. This cost difference declines at 10% per year, truncating benefits in the year 2000. We also assume that 10% of the filter applications use the CANMET supported technology.

EXHIBIT VI-9 Benefit Through Reduced Costs to Meet Environmental Regulations

Year	Annual Conversions	Conversions Using CANMET Technology	Savings Per Conversion (\$'000)	Total Annual Saving (\$'000)	Present Value of Savings (\$'000)
1988					
1989					
1990			9.40		
1991			8.46		
1992			7.52		
1993			6.58		
1994	6000	600	5.64	3,384	2,534
1995	6000	600	4.70	2,820	1,964
1996	6000	600	3.76	2,256	1,462
1997	6000	600	2.82	1,692	1,020
1998	6000	600	1.88	1,128	632
1999	6000	600	0.94	564	294
2000	6000	600	0.00	0	0
Total Benefit					\$7,907

Given these assumptions, we calculate a total benefit through reduced costs required to meet the environmental regulations of \$7.9 million in 1990 dollars.

A benefit will result to Canada to the extent that the selling price of units sold by the Canadian manufacturer exceed the opportunity cost of the resources used to produce these units. At present, few manufacturers produce filters capable of removing the diesel soot. However, this situation cannot be expected to remain indefinitely. Other

firms will enter the market as the demand for filters increases. This will reduce the margin on unit sales through normal competitive actions.

We do not know the actual difference between the selling price and opportunity cost of resources used to produce the filters. We therefore use a conservative estimate of 10% on sales by the Canadian firm prior to 1991. Thereafter the margin is reduced, through competitive forces, until the year 2001 when the margin is assumed to be zero. This results in a present value of \$4.0 million as shown in Exhibit VI-10.

EXHIBIT VI-10 Benefit Through Sales at Prices Above Opportunity Costs

Year	Annual Sales	Assumed Margin on Sales	Benefit From Sales	Present Value of Savings
	(\$'000)	(%)	(\$'000)	(\$'000)
1988	0.75	10	0.08	0.09
1989	1.1	10	0.11	0.12
1990	1.5	10	0.15	0.15
1991	6.5	8	0.52	0.48
1992	6.5	8	0.52	0.45
1993	6.5	8	0.52	0.42
1994	12.0	6	0.72	0.54
1995	12.0	6	0.72	0.50
1996	12.0	6	0.72	0.47
1997	12.0	4	0.48	0.29
1998	12.0	4	0.48	0.27
1999	12.0	2	0.24	0.13
2000	12.0	2	0.24	0.12
2001	12.0	0	0.00	0.00
			Total	\$4.01

4. Summary of Benefits and Costs

Benefits of the diesel exhaust cleaning technology are estimated at \$26.6 million in 1990 dollars. These benefits result from the following impacts:

- Reduced maintenance costs of underground equipment \$12.6 million.
- Reduced carcinogenic risk -- \$2.1 million.
- Reduced cost to meet regulatory requirement -- \$7.9 million.
- Sales impact -- \$4.0 million.

We reduce this total benefit by research costs borne by the private sector. Thus, we deduct expenditures by the Ontario Ministry of Labour (\$300,000), NRC/PICP (\$300,000) and equipment manufacturers and mine operators (\$1,000,000). The present value of these costs is \$2.8 million. The remaining benefit to Canadian society is \$23.8 million.

This benefit results from research cost incurred by CANMET of \$3.5 million in 1990 dollars. The net benefit of the project is therefore \$20.3 million in 1990 dollars.

5. Results of validation

Respondents to our validation exercise felt the project had been worthwhile to society. Many commented that more work was required in the area since the technology could not be used by all diesel engines. Many respondents also felt uncomfortable with our attempts to quantify human life or place a value based on a **potential** human carcinogen.

Based on the validation results, we revised downward our estimate of the value of a reduced carcinogenic risk by \$0.35 million. This revision is as a result of using an estimate of 75% of respirable combustible dust being diesel soot (as found in the Brunswick study) instead of our implicit 100% used previously in our calculation.

Respondents were least comfortable with our estimate of the annual savings in maintenance costs of underground equipment. These savings were estimated based on a study in the Brunswick mine. We use the average of a two year life for filters based on more recent data than provided in the study. However, the Brunswick mine represents an atypical situation. Cost savings for other mines are expected to be much lower. We estimate this annual maintenance reduction in mines other than the Brunswick mine as \$100,000, based on further conversations. This is applied to five mines who have installed the filters in Canada.

VII

PROJECTS OF THE MINERAL SCIENCES LABORATORIES

A. INTRODUCTION

This chapter presents the costs and benefits of two projects of the mineral sciences laboratories:

- Bioleaching of uranium.
- Supplementary cementing technology.

B. BIOLEACHING OF URANIUM

1. Background

Bioleaching of uranium is a project developed jointly by CANMET and Denison Mines to use a naturally occurring bacteria, *Thiobacillus ferrooxidans*, to extract uranium from low grade ore. The process can best be described by considering the two ore zones which exist at Denison. One is the high grade zone which is typically three metres deep and contains 1.8 lbs/ton of U_3O_8 (uranium oxide). This is overlain by approximately 2 metres of barren rock. A second low grade zone approximately 4 metres thick and containing 0.75 lbs/ton U_3O_8 , lies above that.

During normal operation of the mine the high grade ore zone is mined and transported to the surface for uranium recovery in the treatment plant. This conventional mining process consists of the following steps:

- Grinding of the ore.
- Thickening and filtration of the ore.
- Leaching of the ore with sulphuric acid.
- Partial neutralization of the leached slurry.
- Solid-liquid separation of the uranium bearing solution.
- Loading of the uranium onto resin.
- Stripping of the uranium from the resin.
- Gypsum removal and uranium precipitation from the strip solution.
- Thickening, filtration, drying and packing of the uranium.

- Tailings neutralization.
- Tailings deposition.

The underground bacterial leaching process involves blasting of the low grade ore down into the space previously occupied by the high grade ore. A bulkhead is then constructed at the low end of the stope to contain the ore and leach solution. The stope is flooded with mine water containing the naturally occurring bacteria. The stope is then drained to allow the bacteria to partially oxidize the sulphide portion of the ore to sulphuric acid and $\text{Fe}_2(\text{SO}_4)_3$, which in turn dissolves the uranium.

For the process to occur there should be an adequate supply of nutrients such as nitrates and phosphates as well as sufficient oxygen and carbon dioxide. The leaching process takes approximately two years. During that time the stopes are periodically refilled and drained to maintain the leaching process. A large number of stopes are undergoing leaching at any one time and a portion of the mine water is continually pumped to surface for uranium recovery. The mine water is used as process water in the grinding circuit.

2. Costs

CANMET conducted research on the bioleaching of uranium in the late 1960's and early 1970's. Approximately 0.5 person-years were devoted to the research each year between 1964 and 1973, inclusive. CANMET involvement also included a staff person acting in a scientific advisor capacity to the project between 1985 and 1988. This commitment is estimated at 0.1 person-years each year.

Exhibit VII-1 calculates the present value of the person-year commitment by CANMET staff to the project at \$2.5 million (in 1990 dollars). An opportunity cost of \$100,000 (in 1990 dollars) is assigned per person-year devoted to the research.

In addition to the costs incurred by CANMET, Denison Mines is estimated to have incurred costs of \$1.05 million and the NRC-IRAP program an additional \$1.06 million. These costs are incurred between 1984 and 1988. In 1990 dollars, they represent costs of approximately \$2.8 million.

3. Benefits

Successful development of the bioleaching technology at the Denison Mine means that a former resource, that is uneconomical to exploit using other methods, is made available to the firm. This has three impacts:

- A saving occurs as the costs to produce output using the technology is less than the costs that would be incurred to produce the same output using the next best available technology. This next best alternative for Denison is the extraction of high grade ore using conventional techniques and use of the inefficient grinding and crushing plant. This cost saving is a benefit for society.

EXHIBIT VII-1 Present Value of Costs of CANMET Involvement

Year	CANMET Staff Complement (PY)	Annual Cost (\$'000)	Present Value of Cost (\$'000)
1964	0.5	50	328
1965	0.5	50	305
1966	0.5	50	284
1967	0.5	50	264
1968	0.5	50	245
1969	0.5	50	228
1970	0.5	50	212
1971	0.5	50	198
1972	0.5	50	184
1973	0.5	50	171
1974	0.0	0	0
1975	0.0	0	0
1976	0.0	0	0
1977	0.0	0	0
1978	0.0	0	0
1979	0.0	0	0
1980	0.0	0	0
1981	0.0	0	0
1982	0.0	0	0
1983	0.0	0	0
1984	0.0	0	0
1985	0.1	10	14
1986	0.1	10	13
1987	0.1	10	12
1988	0.1	10	12
Total	5.4		\$2,470

- The bioleaching process displaces extraction of ore and surface grinding and crushing. In so doing, it defers costs needed to neutralize tailings from this process. A benefit results as the deferred costs have less impact on society than if incurred sooner.
- The useful life of the mine is extended resulting in longer term benefits.

Each impact is quantified below.

a) Cost Savings on Output Produced Through Bioleaching

Denison Mines produced approximately 654,000 lbs. of uranium oxide in 1988, 550,000 lbs. in 1989, and is expected to produce 640,000 lbs. in 1990, using the bioleaching process. By comparison approximately 2,900,000 lbs. will be produced in 1990 using conventional methods of extraction, grinding and treating. Because of the output produced by the bioleaching process, Denison was able to decommission its old crushing and grinding plant and operate its low-cost SAG mill only. The SAG mill has an absolute capacity that depends on the grade of the ore being mined. At current grades, the SAG plant has an absolute capacity of 4,200,000 lbs. annually, implying that desired output of greater than this amount can only be produced using extraction techniques and the old plant or bioleaching. The savings in costs on the output produced by the bioleaching process instead of the old mill thus represent a cost savings or benefit of the process. This saving is illustrated as the shaded area in Exhibit VII-2.

Exhibit VII-3 presents our estimate of the costs to produce a pound of uranium oxide using the bioleaching process. These costs should be viewed as marginal to the existing operation of Denison Mines. For example, no cost has been included to dig the existing stopes. Conversion from \$/ton of ore to \$/lb. U_3O_8 assumes a grade of 0.75 lb. U_3O_8 /ton and recovery of 76%. All other assumptions are presented in the exhibit.

As the exhibit illustrates we estimate a cost of \$16.18 per pound of uranium oxide produced using the bioleaching process¹. (Note that this price is above the current spot price for uranium. We understand that contracts in the industry tend to be long term and typically have values which exceed the current spot prices.) Without this technology, Denison Mines would be forced to use its old inefficient mill for production above the capacity constraint of its efficient SAG plant. Production costs at Denison are confidential. However, to estimate the cost of extraction and operation of the old mill we make the conservative estimate that costs would be \$4.00 more per pound or at least \$20.18/lb U_3O_8 .

Total annual benefits through the process, thus become the difference between the costs of the production methods (\$4 per pound) multiplied by the number of pounds produced annually (640,000 lbs. in 1990). Thus, total benefits are estimated at \$2.6 million in 1990 for the process.

¹We assume a stope size of 10,000 tons in our calculation. Some stopes are larger. To the extent that the average stope size is greater than 10,000 tons some of our cost items are over-estimated. This would tend to over-estimate the costs of bioleaching and consequently under-estimate benefits of the process. We have reviewed our estimate of the costs of the bioleaching process with Denison Mines and have obtained their approval of our estimates.

EXHIBIT VII - 2 Cost savings resulting from bleaching process

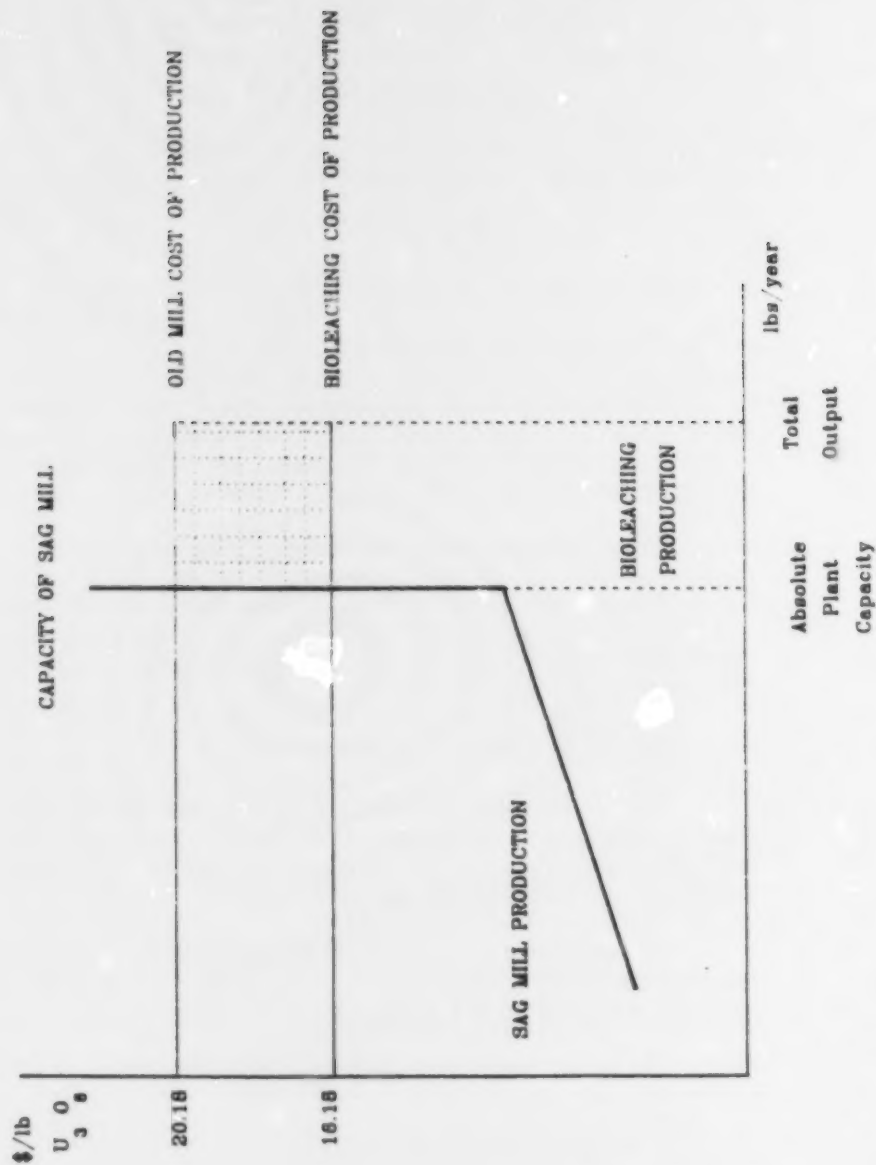


EXHIBIT VII-3 Cost Per Pound of Uranium Oxide Produced Through Bioleaching Process

Cost Area		\$/Ton	\$/lb U ₃ O ₈
Mining		2.50	
Bulkhead		3.50	
Solution Pumping	- Power	0.68	
	- Maint.	0.53	
Aeration	- Power	0.13	
	- Piping	0.20	
Ventilation	- Power	0.04	
	- Piping	0.18	
Labour		0.60	
Surface Treatment		0.86	1.50
Total		9.22	16.18

The following calculations and assumptions are relevant:

➤ **Mining of the Low Grade Ore**

The mining process has been analyzed using a description of the mining methods and equipment contained in the Denison reports. Typical labour and material costs were used and the cost of blasting the low grade ore down into the space previously occupied by the high grade ore has been estimated at \$2.5/ton.

➤ **Construction of the Concrete Bulkhead**

The present cost of constructing the concrete bulkhead was given by Denison as \$35,000. This has been significantly reduced as more experience was gained during the development of the project. A stope typically contains 10,000 tons and the bulkhead costs are therefore \$3.50/ton.

➤ **Solution Pumping Costs**

Prior to the introduction of the underground leaching programme, mine water still had to be pumped to surface as part of the dewatering programme necessary to mine the high grade ore. Therefore the only costs applicable to the leaching programme are those associated with filling and draining the stopes.

The combined horsepower of these pumps is 1,000 hp for 90 stopes. Assuming a leaching period of 2 years, a power cost of \$0.047/kWh and a stope capacity of 10,000 tons, this is equivalent to a power cost of \$0.68/ton.

The maintenance costs of these pumps is estimated at \$20,000/month or \$0.53/ton.

EXHIBIT VII-3 Cost Per Pound of Uranium Oxide Produced Through Bioleaching Process (cont'd)

> Aeration of the Stopes

The stopes are aerated by 2" plastic pipes which are laid along the floor of the stope prior to blasting and are cast through the concrete bulkhead. Assuming a pipe cost of \$10/metre and that 200 metres are used in a stope the pipe costs are \$0.20/ton.

The fans supplying the air consume 2.10 hp/stope or \$0.13/ton.

> Ventilation of the Stopes

As radon gas is released, a ventilation system is required.

The ventilation fan consumes 0.70 hp/stope or \$0.04/ton. Also, 16" FRP pipe is used at a rate of 0.006 metres/ton and a cost of \$30/metre. This is equivalent to \$0.18/ton.

> Labour

The labour required to mine the ore is included in the mining cost estimate. Also the construction labour is included in the bulkhead cost.

A crew of 15 workers complete the other various activities involved in leaching. Assuming an hourly rate of \$20, a payroll burden of 35% and an annual treatment rate of 1.4 million tons/year, this is equivalent to \$0.60/ton.

> Surface Treatment Costs

As the surface treatment plant already has sufficient labour to produce uranium from the high grade ore as well as from underground leaching, only the incremental reagent costs are applicable to uranium production from leach solution. These are estimated as follows:

Item	Cost \$/lb U ₃ O ₈	Source
Crushing & Grinding (lime)	0.42	(Calculated)
Leaching (Sulphuric Acid)	0.35	(Calculated)
Ion Exchange (Resin)	0.008	(Based on Jan-June 1989 figures)
Precipitation (Nitric Acid/Ammonia)	0.29	(Based on Jan-June 1989 figures)
Drying and Packing (Drums)	0.008	(Based on Jan-June 1989 figures)
Neutralization (Lime)	0.42	(Calculated)
Total	1.50	

> Conversion Factors

The conversion from \$/ton to \$/lb U₃O₈ assumes a grade of 0.75 lb U₃O₈/ton and a recovery of 76%.

CANMET should not be attributed with this entire benefit in all future years. Bioleaching is a recognized technology in the mining industry. Denison had been working on the process prior to the involvement of CANMET. However, the CANMET involvement in the project has been credited with a speed up of the output that Denison was able to achieve using the process.

To assess the attributable impacts to CANMET we have assumed that Denison would have only been able to produce the following outputs of uranium oxide, by project year, without the help of CANMET:

- Year 1 120,000 pounds
- Year 2 120,000 pounds
- Year 3 120,000 pounds
- Year 4 120,000 pounds
- Year 5 120,000 pounds
- Year 6 120,000 pounds
- Year 7 240,000 pounds
- Year 8 360,000 pounds
- Year 9 480,000 pounds
- Year 10 600,000 pounds

The uranium industry in Canada has recently entered a contractionary phase. As a result, it is now estimated that no more than 250,000 pounds of uranium will be required through the bioleaching process in future years. We therefore cap the expected future output of the bioleaching process with and without the CANMET involvement at 250,000 pounds annually.

Exhibit VII-4 estimates the benefit of the impacts attributable to CANMET. As the exhibit illustrates these benefits have a present value of \$7.8 million in 1990 dollars.

b) Reduced Cost to Neutralize Tailings.

Tailings brought to the surface must be neutralized to make them environmentally safe. We estimate that this cost is about \$0.55 per pound of output to treat tailings from output milled above ground. We use this number to help estimate the extra cost needed to treat the tailings from output that would be brought to surface without the CANMET project.

EXHIBIT VII-4 Benefit Through Cost-Savings on Output Produced Through Bioleaching

Year	Output with CANMET (⁰⁰⁰ lb)	Output without CANMET (⁰⁰⁰ lb)	Incremental Output (⁰⁰⁰ lb)	Value of Cost Savings (\$/lb)	Total Value of Savings (\$ ⁰⁰⁰)	Present Value of Savings (\$ ⁰⁰⁰)
1988	654	120	534	4.00	2,136	2,468
1989	550	120	430	4.00	1,720	1,849
1990	640	120	520	4.00	2,080	2,080
1991	250	120	130	4.00	520	484
1992	250	120	130	4.00	520	450
1993	250	120	130	4.00	520	419
1994	250	240	10	4.00	40	30
1995	250	250	0	4.00	0	0
Total Benefit						\$7,780

Exhibit VII-5 repeats the calculation of annual incremental output produced as a result of CANMET's involvement in the bioleaching project. This output does not need to be produced through conventional mining and milling. As a result costs of tailings neutralization are avoided until such time as the deferred output is produced through conventional methods. As Exhibit VII-5 shows this occurs in the year 2005.

We estimate the amount of "conventional" output deferred to the year 2005. (In the year 2005 this amount is negative as the deferred output of 3.6 million pounds is produced in this year.) We use this amount to multiply by our costs of treating the tailings from above ground output. This produces a treatment cost avoiding, from 1988 to 1994 inclusive, and a treatment cost incurred, in the year 2005. As Exhibit VII-5 illustrates the value of this deferred tailings treatment cost is \$0.7 million.

c) Extended Life of Mine

The bioleaching process produces uranium oxide from ore that would not be exploited using conventional techniques. CANMET's involvement results in the bioleaching process displacing production using high grade ore sooner than would occur without CANMET's involvement. Based on data presented earlier, we estimate that 1,884,000 pounds of uranium oxide would need to be produced using conventional methods to match the shortfalls in production from the bioleaching process without the CANMET involvement. This is slightly less than one year's production for Denison at current production levels. This extra production would extend the expected 15-year future life of the mine by approximately one year.

This benefit would be equal to the difference between the selling price obtained by Denison for this extra 1,884,000 pounds of U_3O_8 and the opportunity cost of producing this uranium oxide using the best available technology at the time. This may be the SAG plant. If so, its opportunity cost would be low as the extra production

EXHIBIT VII-5 Benefit Through Reduced Water Treatment Costs on Output Produced Through Bioleaching

Year	Output with CANMET (^{'000} lb)	Output without CANMET (^{'000} lb)	Incremental Output (^{'000} lb)	Treatment Cost Per Pound (\$)	Treatment Cost Avoided (\$ ^{'000} lb)	Present Value of Savings (\$ ^{'000} lb)
1988	654	120	534	0.55	294	339
1989	550	120	430	0.55	237	254
1990	640	120	520	0.55	286	286
1991	250	120	130	0.55	72	67
1992	250	120	130	0.55	72	62
1993	250	120	130	0.55	72	58
1994	250	240	10	0.55	6	4
1995	250	250	0	0.55	0	0
1996						
1997						
1998						
1999						
2000						
2001						
2002						
2003						
2004						
2005			-1,884	0.55	-1,036	-350
Total Benefit						\$720

would in fact postpone the date of decommissioning, and presumably zero economic value, by approximately one year. Labour inputs used to produce the output would, however, have a positive opportunity cost associated with their use. We also do not have information on the selling price obtained by Denison per pound of uranium oxide. Thus, our estimate of the difference between selling price and opportunity cost for these extra units of production is somewhat uncertain. As a result, we use a conservative value of \$5 per pound, measured in 1990 dollars. The value of this extra production, assumed to occur in the year 2005, is \$3.2 million, in 1990 dollars.

4. Summary

Incremental benefits of the CANMET involvement in the bioleaching of uranium project are expected to yield a benefit of \$11.7 in 1990 dollars. This benefit is a result of:

- Cost savings on output produced through bioleaching -- \$7.8 million.
- Cost savings through deferred tailings treatment -- \$0.7 million.
- Extended life of mine -- \$3.2 million.

From these total attributable benefits we deduct research costs incurred by Denison Mines and NRC-IRAP. (These were estimated earlier to have a present value of \$2.8 million.) The remaining benefit is \$8.9 million.

Incremental costs of the involvement by CANMET in the project have a present value of \$2.5 million. The net benefit to Canada is therefore estimated at \$6.4 million in 1990 dollars.

It should be noted that the net benefit of the project would be much higher except for the recent downturn in the market for uranium. The project would have had a net benefit to Canada closer to \$15 million if sales of uranium had continued as expected at the start of the project.

5. Results of validation

The downturn in the uranium industry affected the validity of our original assumptions concerning the future benefit of bioleaching. Our validation exercise allowed us to revise our assumptions to reflect the most recent estimates of future production from bioleaching. As a result, the revised benefits are less than those previously identified. However, should the uranium industry outlook improve, bioleaching will once more become more significant to Denison Mines.

C. SUPPLEMENTARY CEMENTING MATERIALS

1. Background

This section discusses the costs and benefits of CANMET activities devoted to the investigation of Supplementary Cementing Materials. Unlike other projects discussed in this report, these activities would more correctly be described as a collection of projects. However, they are all devoted to research on supplementary cementing materials and are therefore treated as one project for review purposes.

For ease of discussion in this section we have grouped the impacts of the research into three areas:

- Displacement of high value cement by lower valued substances.
- Costs avoided.
- Other impacts.

a) Displacement of high value cement

Recent data suggest that approximately 10 million tonnes of portland cement are used annually in Canada at a value of \$1 billion.¹ The displacement of cement by less valuable substances can potentially lead to large savings.

CANMET has had a number of breakthroughs in cement technology that have resulted in the potential displacement of cement by other substances.

- CANMET contributed to the establishment of a granulated blast furnace slag plant. The slag is a by-product of a blast furnace and in some applications can displace up to 90% of cement. Displacement of 25% to 50% is more typical.
- Fly-ash is a waste by-product primarily from coal-burning power stations. In normal applications it has the potential to displace between 15% to 20% cement. CANMET has contributed to the knowledge of the use of suitable fly ashes and has been instrumental in promoting the use of fly ash.
- CANMET developed high volume fly ash concrete using 60% fly ash.

b) Costs avoided

CANMET research has made it possible to reduce costs in other areas related to the use of cement:

- CANMET and the University of Sherbrooke have conducted research on silica fume concrete. The concrete incorporating silica fume has very low permeability. This makes it ideal to repair bridges with salt damage. Generally, for concreted made without silica fume, there is a 3 to 5 year period before major deterioration sets in. With silica fume, this is anticipated to increased to 15 to 20 years, resulting in a saving in road maintenance. A similar deferral of maintenance costs is possible for parking garages and other structures subject to salt damage.
- CANMET has developed a considerable engineering data base for the production of light-weight concretes. Use of such concretes reduces the weight of slabs and thereby reduces the size of supporting columns in tall structures. This reduces the cost and time involved to build such structures.
- Unlike other concretes, high-volume fly ash concrete does not produce high heat when it cures. Thus, time (and

¹ Statistics Canada (Catalogue 44-250) gives the value of output at \$796 million in 1985 and \$832 million in 1986, a 4.5% increase. Using this percentage increase the value of output should be \$993 million in 1990. We round this value to \$1 billion.

money) spent waiting for ordinary concretes to cool or to provide artificial cooling is avoided.

- The use of high-alkali cement is sometimes problematic in Canada as a result of the "alkalie aggregate problem". Some aggregates, used to make concrete, react with the alkalies in the cement to cause expansion. The problem is most serious in Quebec, followed in decreasing order of severity in the Maritimes, Ontario, and to a lesser degree in the West. The economic cost of problems related to concrete subject to the alkali aggregate problem are large. CANMET helped map those areas of the Maritimes where aggregate could be subject to the alkali problem. In addition, supplementary cementing materials developed and promoted by the project help to control this problem when used in concrete. Both actions should help reduce the economic loss due to the alkali aggregate problem in the future.
- Accelerated testing methods have been developed by CANMET which reduce the time interval before testing from 28 days to 28.5 hours. This reduced time interval means that a potential problem is identified sooner allowing less expensive correction of the problem. Improved safety results as problems are identified earlier.
- CANMET also developed non-destructive testing methods that avoid the physical destruction of the item being tested. This results in a saving in the value of the tested item.
- CANMET has made significant contributions to the development of standards on the non-destructive testing of concrete, superplasticizers, supplementary cementing materials and testing. These standards facilitate trade. They reduce the transaction costs of business and reduce contractional uncertainties.

c) Other impacts

The CANMET developed and promoted supplementary cementing technologies have improved properties over conventional cements. These include low permeability, increased durability, high strength, low heat of hydration, crack resistance and others. These features provide benefits in particular applications such as in massive concrete structures such as thick foundations, thick columns and dams.

CANMET has transferred supplementary cementing technology through organized seminars, workshops, and national and international conferences. As a result of this action the timing of the benefits of these developments has been considerably accelerated.

As a side benefit, CANMET has also been instrumental in a Canadian company's entry into the production of superplasticizers thereby displacing

Japanese and German imports of the substance. The company has since entered the export market for the product. Superplasticizers must be used in high-fly ash and in silica fume concrete. They may also be used in other cements improving the flow characteristics of the resulting concrete.

2. Costs

Costs of the CANMET activities devoted to Supplementary Cementing Materials are estimated at \$8.2 million. This estimate assumes an average annual staff complement of 6 between the years 1983 and 1989, inclusive. Each person-year is assumed to have an opportunity cost of \$100,000. Contracts in support of the project are valued at cost. Exhibit VII-6 presents detail on the calculation of the present value of CANMET costs devoted to the project. In addition, private sector firms and various government organizations contributed about \$855,000 to the CANMET research effort in the past 3 to 4 years. This represents a present value of approximately \$1 million.

EXHIBIT VII-6 Present Value of Costs of CANMET Involvement in Supplementary Cementing Materials

Year	CANMET Staff Complement	Annual Staff Cost	Value of Contracts	Total Annual Cost	Present Value of Cost
	(PY)	(\$'000)	(\$'000)	(\$'000)	(\$'000)
1983	6	600	100	700	1,161
1984	6	600	100	700	1,080
1985	6	600	350	950	1,364
1986	6	600	350	950	1,269
1987	6	600	400	1,000	1,242
1988	6	600	400	1,000	1,156
1989	6	600	300	900	968
Total	42	—	—	—	\$8,240

3. Benefits

The benefit impacts of the CANMET activities related to Supplementary Cementing Materials are numerous. For only some of them is it possible to calculate their value. In this section we present our estimate of the benefits of the project that are possible to quantify. We also estimate the likely size of the total benefits of the CANMET activities.

a) Displacement of high value cement by lower valued cementing materials

As mentioned earlier, the CANMET activities have developed and promoted supplementary cementing materials that can displace cement. These

supplementary materials have an opportunity cost to society lower than the opportunity cost of the cement they displace. As a result, displacement of cement by these materials results in a benefit to Canada.

This benefit is calculated in Exhibit VII-7. For each supported material, the exhibit calculates the tonnes of cement sold each year, with and without CANMET's intervention. (These annual numbers are presented by period -- 1990, 1991-1995, 1996-2000, 2001-2010, and 2011-2020.) The two annual numbers are netted to obtain the likely sales increase that results with the CANMET assistance. This net amount is further reduced to reflect the sales increase that can be attributed to CANMET. The result is an annual sales figure that is attributed to the CANMET supported technology.

Two features related to the attribution of project results are apparent from the exhibit:

- CANMET advances the timing (penetration) of the technologies. Only the net impact related to timing is attributed to CANMET.
- Only part of the remaining benefit is attributed to CANMET. The benefit is reduced by that portion which is believed to be the result of CANMET's support. For blast furnace slag 50% of its use is attributed. Fifty per cent of the use of fly ash in cement is also attributed to CANMET. High-volume fly ash is expected to double the use of fly-ash used to displace cement. This development is as result of CANMET. As a result, 100% attribution is made.

The value assigned to this incremental output is estimated based on the difference between the opportunity cost of the cement displaced and the opportunity cost of the material doing the displacement. In dollars per tonne the calculation is:

$$(\text{Value of cement} - \text{Value of replacement substance}) * (\% \text{ of displacement})$$

The value of cement is assumed to be \$100 per tonne in the calculation. (This represents the shipment value of standard portland cement in bulk.) The value of blast furnace slag is given by the real resources used to produce the slag. This ranges between \$25 to \$35 per tonne. (The price of blast furnace slag is \$85 to \$90 per tonne. However, this price includes a surplus to the producer.) Fly ash is assumed to have an economic value of minus \$10 per tonne. This represents the cost for disposal of the fly ash in the absence of its use in cement. No alternative use offering a positive value for the fly ash is available other than in cement. (In some instances it is used as a fill material but at very low value.)

All values tend to fluctuate graphically. We use typical values of cement and supplementary cementing materials in areas where the displacement is likely to occur.

EXHIBIT VII-7 Benefit Through Displacement of High Value Cement by Lower-Valued Material

Material	Value at ¹ \$/tonne	Attribu- tion to CANMET	Impact with/ without CANMET	'000's Tonnes of Cement Sold Annually by Period					
				1990	1991-1995	1996-2000	2001-2010	2011-2020	
Blast Furnace Slag	\$27.20	0.5	With	450	1,000	2,000	3,500	3,500	
			Without	300	500	1,000	2,000	3,500	
			Net By CANMET	150	500	1,000	1,500	0	
Fly Ash	\$27.20	0.5	With	75	250	500	750	0	
			Without	\$2,040,000	\$6,800,000	\$13,640,000	\$20,400,000	\$0	
			Net By CANMET	15	30	40	45	45	
High-Volume Fly Ash	\$19.25	0.5	With	0	0	15	30	45	
			Without	15	30	25	15	0	
			Net By CANMET	7.5	15	12.5	7.5	0	
Total Annual Impact	\$66.00	1.0	With	\$144,375	\$288,750	\$240,625	\$144,375	\$0	
			Without	30	60	80	90	90	
			Net By CANMET	15	30	40	45	45	
Total Annual Impact	\$66.00	1.0	With	\$990,000	\$1,980,000	\$2,640,000	\$2,970,000	\$2,970,000	
			Without	15	30	40	45	45	
			Net By CANMET	\$3,174,375	\$9,068,750	\$16,480,625	\$23,514,375	\$2,970,000	

¹Value of displacement, in dollars per tonne are calculated as follows:

$$[(\text{Value of cement}) - (\text{Value of replacement substance})] / (\% \text{ of displacement})$$

For each substance this becomes:

$$\begin{aligned} \text{Blast furnace slag:} & [(\$100) - (\$27.5)] / (.375) = \$27.20 \\ \text{Fly ash:} & [(\$100) - (\$10.00)] / (.175) = \$19.25 \\ \text{High-volume fly ash:} & [(\$100) - (\$10.00)] / (.60) = \$66.00 \end{aligned}$$

Averages are used for the range of displacement possible using the substance and value of substance.

As Exhibit VII-7 illustrates the annual benefit through displacement of high value cement by lower valued material, attributable to the CANMET support has a value of:

- \$3.2 million in 1990.
- \$9.1 million between 1991 and 1995, inclusive.
- \$16.5 million between 1996 and 2000, inclusive.
- \$23.5 million between 2001 and 2010, inclusive.
- \$3.0 million between 2011 and 2020, inclusive.

The present value of this stream of benefits is \$169.4 million in 1990 dollars.

b) Maintenance costs avoided through use of silica fume cement

Use of silica fume cement will defer future maintenance costs of bridges, parking garages or other structures subject to salt damage. Major deterioration generally results after 5 years in structures made with normal concretes. However, the time until major deterioration is generally 15 to 20 years with concretes made with silica fume cements.

In the United States, silica fume sells at a \$200 U.S. premium compared to normal cements. (A premium of up to \$1,100 U.S. has been paid for silica fume.) This premium represents the addition willingness to pay by the construction industry to obtain the added benefits of silica fume. It represents the present value of the deferred maintenance costs related to the use of silica fume.

In Canada, silica fume cement is no more costly than regular cement. However, the same benefit of deferred maintenance costs exist. As a result the same premium representing the additional willingness to pay for these benefits can be applied to sales of silica fume cement attributable to CANMET.

Industry representatives were unable to validate our assumption concerning the appropriate premium for silica fume cement. As a check on this value, we present the following analysis.

If the use of silica fume cement defers repair work from 5 years after construction to 17.5 years after construction, the present value of this deferral is worth \$0.39 for every \$1 of repair cost incurred. Cement costs are typically a small component of repair costs. Other costs, such as labour, lost revenue (in the case of a garage), time costs (in the case of a bridge), or other costs, are typically a much higher percentage of total repair costs. If these other repair costs to the cost of cement are 5:1 (i.e., \$500 other costs per \$100 cost of cement), the appropriate premium is \$235 ($\$600 \times 0.39$). If the proportion of other costs to cement costs exceeds 5:1, a higher premium is warranted. A 10:1 proportion is not out of line with normal repair work. Thus, our \$235 premium is a conservative estimate of the value of silica fume cement.

In Exhibit VII-8 we estimate the annual attributable benefit for silica fume cement. This calculation is similar to that of Exhibit VII-7. In Exhibit VII-8 CANMET is attributed with 75% of the six year timing advance. The annual incremental sales of 20,000 tonnes are assumed to have a value, as discussed earlier, of \$235 (Cdn). This results in an annual attributable benefit of \$3.5 million between 1990 and 1995, inclusive. The net present value of this stream of benefits is \$17.8 million.

c) Sales impact of superplasticizers

CANMET assisted a Canadian firm enter the market for superplasticizers. CANMET's technical initiatives reduced the time needed by the firm to enter the market. CANMET helped "open doors" for the new firm in domestic and foreign markets. This accelerated the development of the firm.

The firm has been successful in displacing imports of superplasticizers by Japanese and German firms. As a result it maintains a virtual monopoly in the Canadian market. Since that time the firm has expanded into the U.S. market. Some of the margin on sales of the firm should be attributed to the work of CANMET.

We have assumed that a maximum of 50% of the margin on sales of superplasticizers by the firm should be attributed to CANMET. This attribution is reduced to zero in the year 2000. The firm's margin on sales (price above opportunity cost) is conservatively estimated at 10%. Although the firm has a virtual monopoly its rapid growth suggests that it is not exploiting its potential monopoly power. Based on these assumptions benefits attributable to CANMET are conservatively estimated at \$4 million. (We have not presented sales data for the firm to protect the confidentiality of these numbers.)

d) Other benefits

We have estimated the value of some benefit impacts of the CANMET research on Supplementary Cementing Materials. As noted above, these are estimated to have a value of \$191.2 million.

We are unable to be as definitive concerning other benefit impacts. These impacts include:

- Alkalie aggregate problem.
- Light-weight concretes.
- Improved testing methods.
- Standards development.
- Improved properties of cements not noted earlier, resulting in better concretes, and reduced repair costs.

EXHIBIT VII-8 Benefit Through Costs Avoided Through Use of Silica Fume Cement

Material	Value at \$/tonne	Attribu- tion to CANMET	Impact with/ without CANMET	'000's Tonnes of Cement Sold Annually by Period				
				1990	1991-1995	1996-2000	2001-2010	2011-2020
Silica Fume			With	20	20	20	20	20
			Without	0	0	20	20	20
			Net	20	20	0	0	0
		0.75	By CANMET	15	15	0	0	0
	\$235.00			\$3,525,000	\$3,525,000	\$0	\$0	\$0

1 Value is estimated based on prices for silica fume cement in the U.S. There silica fume cement costs \$300/ton (U.S. dollars). Prices as high as \$1,200 per ton have occurred. We assume that in the U.S. better information results in a price reflecting the products actual value. This difference (\$735 Cdn.) between the value of silica fume and ordinary cement represents the present value of the repair costs avoided through use of silica fume cement.

- Improved safety related to better testing methods and improved properties of cements.
- Transfer of technology accelerating the use of materials not otherwise listed.

To estimate the value of these additional benefits we assume that each year they represent one-half of one per cent of the annual economic value of production for the cement industry. The value of production is currently \$1 billion and is expected to grow at the real rate of growth of the economy -- 1.7% per annum. These assumptions result in an annual benefit of \$5 million in the year 1990 growing to \$7 million (in 1990 dollars) in the year 2010. We think that this is an extremely conservative estimate of the likely benefit attributable to the CANMET contribution in the above areas. This benefit is assumed to occur between 1990 and the year 2010. Given these assumptions the net present value of the benefit in the above areas is \$63.8 million.

In our validation exercise, no respondent suggested that a lower percentage be used. Three individuals thought a higher percentage should be used. One estimated a value of three-quarters of one per cent. The others, although unable to estimate a value, thought ours was "extremely undervalued," and "low."

e) Total benefits

Total benefits of the CANMET research related to Supplementary Cementing Materials are conservatively estimated at \$255.0 million in 1990 dollars. This benefit is a result of:

- Displacement of high value cement by lower valued materials -- \$169.4 million.
- Maintenance cost avoided through use of silica fume cement -- \$17.8 million.
- Sales impact of superplasticizers -- \$4.0 million.
- Other benefits not estimated earlier -- \$63.8 million.

4. Summary

Total benefits of the project are estimated at \$255.0 million. This represents a minimum estimate of the project's benefits. The private sector and various government agencies (other than CANMET) contributed approximately \$1 million to the research effort. The remaining benefit is therefore \$254 million. Costs of the CANMET research to attain these benefits are \$8.2 million. The net present value of the project is therefore conservatively estimated at \$245.8 million.

5. Results of validation

Those who responded to our validation questionnaire were generally in agreement with the assumptions of our analysis. A minority thought our \$100 estimate for the value of cement as an input reflected the retail price of cement. If so, this value was not

comparable with our estimate for the value of supplementary cementing materials. We checked this datum. The \$100 estimate reflects the average value of shipments for a tonne of bulk cement at the manufacturer's door. As a result, it is comparable with other data. A minority identified some assumptions that should be revised in CANMET's favour. The majority agreed with the assumptions as presented. As a result, we did not alter any values based on these minority opinions.

All agreed with our overall assessment that the project has been worthwhile to society. A minority felt that our net benefit estimates were undervalued.

Some also commented that our analysis, conducted on a national basis, overlooked the international contribution made by the project. Singled out was a country such as India, which produces 40 times as much fly ash as it consumes, and faces energy costs two to three times those of Canada. Also mentioned were China, Turkey, Russia and Poland, with severe shortages of cement from traditional materials. If such benefits to countries other than Canada were included, the net benefit would be significantly increased.

VIII

COAL RESEARCH LABORATORIES

A. INTRODUCTION

In this chapter we review one project of the Coal Research Laboratories -- Monolithic Packing Technology.

B. MONOLITHIC PACKING TECHNOLOGY

1. Background

The basis for the monolithic packing technology dates to pre-war Germany. With the occupation of the coal fields in the Ruhr Valley by the British Army, the technology was transferred to British Coal. Since that time, British Coal and its consultants became the recognized experts for this technology throughout the world.

Impetus for the study by CANMET resulted from a request by the Cape Breton Development Corporation (CBDC). CBDC operates 3 of the 4 underground coal mines in Canada. The fourth is operated by the Smokey River Coal Company in Grande Cache, Alberta. CBDC's three mines, Phalen, Lingan and Prince, produced an estimated 2,750,000 tonnes of metallurgical and thermal coal for the fiscal year ending 1987.

During the early 1980s, the Lingan Colliery of the Cape Breton Development Corporation experienced problems:

- Ventilation air was rapidly leaking through the gob (waste) causing a daily loss of at least 25 minutes or more per wall. Production scheduling required the simultaneous working of the two adjacent longwall faces. This prevented the use of the cundy ventilation control method historically used in the mine.
- Increased roadway deformation.

Monolithic packing was seen as a potential solution to the problems in the Lingan Colliery. The CBDC did not approach British Coal. Reasons include:

- Cost of consultants estimated at \$200,000.
- Extra costs for travel and accommodation.

- Extended timeframe because consultants are not readily available for meetings and testing.
- CBDC's belief that knowledge must be acquired in Canada and must be capable of transfer to other Canadian operations.

Instead, they approached CANMET with their problem.

CANMET's initial research into monolithic packing technology started in 1982. By 1985, the adapted technology had been perfected and was transferred to the Lingan colliery of CBDC. Monolithic packing is scheduled for use in the Phalen colliery when the depth of cover permits pillarless extraction.

The technology replaces the conventional longwall hardwood solid pack chocks with an impervious wall of bags packed with a mixture of bentonite and high alumina cement plus accelerators creating a monolithic pack.

Advantages of the monolithic packing technology are:

- Reduced ventilation leakage, improving the safety of the mine by reducing methane gas build-up.
- Reduced amount of hardwood packing, and therefore, amount of combustible material in the mine, again improving mine safety.
- Improved shoring technique, improving the roadway, reducing costs and allowing faster extraction of the coal.

In the case of CBDC, the technique may have allowed the mine to continue operation. Problems were encountered with the old technology that made premature closure of the mine likely. This would have resulted in job losses in Cape Breton and loss in the value of the coal resource.

Since the technology transfer in 1985, CBDC and CANMET have been working on a number of refinements and cost reduction experiments such as replacing the imported British packing material with local substitutes. To date, all equipment and packing materials, except for the bags for the packing, are purchased in Britain. A local supplier has been established to produce the packing bags. Promising experiments have been carried out by CANMET and CBDC on substituting a local anhydride (gypsum) material instead of purchasing the high alumina cement from Britain. If tests prove successful, this would create a new local industry.

2. Costs

The CANMET costs of the project are estimated, in Exhibit VIII-1, at \$300,000 in 1990 dollars. These represent the present value of the 1.9 person-years of staff time devoted to the project between 1982 and 1985 inclusive.

YEAR	CANMET Staff Complement	Annual Staff Cost	Present Value of Cost
	(PY)	(\$'000)	(\$'000)
1982	0.1	10	18
1983	0.6	60	100
1984	1.0	100	154
1985	0.2	20	29
Total	1.9		\$300

In addition, some operating costs were borne by CBDL. These costs were:

- \$10,000 in 1983-84.
- \$30,000 in 1984-85.
- \$5,000 in 1985-86.

The present value of these costs borne by CBDL is \$70,000.

3. Benefits

a) Benefit impacts resulting from the technology

The monolithic packing dramatically reduces work stoppages because of poor ventilation in the mine. The improved roadway also speeds production. The Cape Breton Business Development Corporation estimates the increase in production at between 5%-10%. They use a conservative 2.5% production increase in their calculations. Based on this assumed efficiency gain they estimate an annual net benefit to the Corporation of \$319,750 from the Lingan Colliery only. If tests on the local gypsum cement prove successful this net revenue gain would increase to \$443,086.

The monolithic packing technology also reduces the chance of fire in the mine through:

- Improved ventilation.
- Reduce build-up of methane gases.
- Reduced combustible material in the mine through replacement of the hardwood packing by the fire-retardant monolithic pack.

In a 1988 study,¹ Norwest Resources Consultants Ltd. did a review of fires in the Sydney coal field. They examined six major fires in a fifteen year period from 1973 to 1988. The total cost of these fires was established at \$515 million or approximately \$30 million each year. (From a social context these costs are likely under-estimated.) They also reviewed 90 minor incidents from which fire did or could easily have resulted over the three years preceding their study. Each of these incidents was found to have the potential to create a major fire. These incidents were found to incur an annual cost of \$215,000. (Again these costs are under-estimated from a social context.)

The incidence of fire, severity of fires which do result and related costs of fire are all likely to be reduced by the monolithic packaging technology.

The technology is expected to especially reduce the incidence of a major fire. Improved ventilation means less build-up of gases at the working face and therefore less risk of explosion occurring. Since monolithic packing has been used, there have been no fires at the longwall faces. Even if the technology is able to reduce the annual probability of a major fire by only 50% this would result in a saving of \$15 million per year using the Norwest estimates. (As noted earlier, we feel these estimates under-report social values and therefore would under-estimate the benefit of increased safety.)

b) Incrementality

A central issue in benefit-cost analysis is the extent to which benefits should be attributed to a particular project. The central question is: "What would have happened without CANMET's involvement in the project?"

Our answer to this question, based on the available information, is that CBDC would have been forced to buy the monolithic packing technology from British Coal without CANMET. The likely cost of the involvement with the British Coal consultants would have been \$250,000 (\$200,000 consulting fee plus \$50,000 expenses). Assuming the involvement by British Coal would have occurred over the same approximate time frame as the CANMET project these costs represent a present value of \$395,000.

We feel that the benefits of the project in terms of improved roadway, improved ventilation, increased efficiency and improved safety would have been equal with the British Coal consultants. However, there is the possibility that the local presence of the CANMET laboratory contributed in ways that could not have been achieved by a foreign consultant. We cannot quantify this impact.

One impact that we feel would not have resulted with use of the foreign consultants is the domestic sourcing of materials. To date, this has been limited to the manufacture of plastic bags used by the system. If tests prove successful, the local sourcing for the cement used in the pack is possible. These later impacts are incremental. They would not occur without the involvement of CANMET.

¹Northwest Resource Consultants Ltd., "Incidence and Possible Causes of Fires within Coal Mines of the Nova Scotia Coal Fields and on Measures that can be Taken to Prevent such Fires: Stage 1 Socio-economic Impact of Mine Fires." October 1988.

We estimate these incremental benefits as follows:

- \$0 per year annual saving on locally sourced plastic bags. We understand that the locally sourced bags are approximately equal to or more expensive than foreign-sourced product. Bags will no longer be purchased when CBDC switches to locally-sourced cement.
- \$160,000 per year for locally sourced cement. This benefit would begin in 1990 and continue for the expected life of the Lingan Colliery (18 years).

4. Results

A benefit results from the project to the extent that the costs of the CANMET project are less than the costs of the project conducted by foreign consultants. The cost saving is estimated to have a value of \$95,000 in 1990 dollars (\$395,000-\$300,000).

Benefits also result from cost savings through the local sourcing of inputs to the monolithic pack. We assume:

- An 18 year life for the mine (starting in 1990).
- An annual saving of \$160,000 in the year 1990 and beyond through the substitution of a locally sourced cement.

Based on the assumptions we calculate a benefit through local sourcing of \$1.7 million in 1990 dollars (see Exhibit VIII-2).

In some benefit-cost analyses an extra benefit is assigned to incremental jobs in an economic region with high unemployment. The economic rationale given is that the opportunity cost of the labour input (the value of the labour without this incremental employment) is low relative to the wage paid in the incremental job. In a region such as Cape Breton with an unemployment rate of 24% (April 1989, Statistics Canada), the best alternative is often unemployment. If unemployment is the true alternative to this incremental employment the social opportunity cost of the labour input is less than the wage of the job.

Assigning an extra benefit to labour input costs resulting from the local sourcing of materials would result in only a small addition to the benefits already calculated. This is because labour input costs will be a small part of the total costs of these locally sourced inputs. The difference between opportunity cost and wage in the incremental employment is also unlikely to be large relative to the wage cost. Both factors limit the size of this potential benefit.¹ Because of the uncertainty of the benefit and its small size we do not include it in our estimate of the benefits of the project.

¹ Calculating the difference between opportunity cost and wage would ideally require analysis of the Longitudinal File maintained by Employment and Immigration Canada. The file is large and expensive to access. Restrictions also exist on its access. This file maintains the work histories (periods of unemployment, employment and wage) for individuals. Ideally the analysis would identify those individuals hired in incremental jobs. It would analyze their employment experience before the job in

EXHIBIT VIII-2 Benefit Through Cost-Savings on Local Sourcing of Material Costs

Year	Value of Cost Savings (\$'000)	Present Value of Savings (\$'000)
1990	160	160
1991	160	149
1992	160	138
1993	160	129
1994	160	120
1995	160	111
1996	160	104
1997	160	96
1998	160	90
1999	160	83
2000	160	78
2001	160	72
2002	160	67
2003	160	62
2004	160	58
2005	160	54
2006	160	50
2007	160	47
2008	160	44
	Total Benefit	\$1,713

As a result, the total benefit of the Monolithic Packing Technology Project are estimated to have a present value of \$1.8 million in 1990 dollars (\$0.1 million research cost saving and \$1.7 million through local sourcing). From this total benefit should be subtracted the costs of research borne by CBDC (\$70,000). Thus \$1.7 million represents the remaining benefit of the CANMET research.

question. From this the opportunity cost could be estimated. It is unlikely that the difference between the opportunity cost and wage would exceed 25% of the wage. Assuming 10% of the cement cost and 50% of the plastic bag cost are labour-related, this would result in an extra benefit of \$6,188 per year 0.25 (0.5 x 49,500) before 1990 and \$4000 per year 0.25 (0.1 x \$160,000) in 1990 and beyond. The present value of this additional benefit stream is \$0.07 million in 1990 dollars.

CANMET research costs to obtain this \$1.7 million benefit are estimated at \$300,000. The net benefit of the Monolithic Packing Technology is therefore estimated at \$1.4 million.

5. Results of Validation

The validation exercise did not change our benefit-cost findings. However, an important comment from the validation responses is that our calculations are based on the impacts of the project to date. The project may have future significant spin-off benefits.

The monolithic packing system has proven to be successful for CBDC because it has improved the roadways and ventilation. Based on this success, CBDC is now investigating the possibility of using local cement as a packing material for retreat walls as the Lingam Colliery enters a new phase of extraction. The recent changes in mine design makes monolithic packing a critical factor to the Lingam Mine's future success.

IX

R&D POLICY ISSUES

Here we discuss the significance of the projects under review in the context of prevailing R & D policies of the Federal government. We also discuss how the benefit-cost approach illustrated in the previous chapters can help enhance the project selection and funding process.

A. CANMET IS A TECHNOLOGY CENTRE

The technology centre policy of the Federal Government is intended to commercialize the operation of various federal laboratories by involving clients more fully in the management of technology centres, fostering effective technology transfer from government laboratories and facilitating the gradual privatization of certain centres, where appropriate. Key features of the policy include the establishment of client-led advisory boards, the annual preparation of a comprehensive business plan, increased cost recovery and the provision of a 20% bonus to centres, based on cost recovery revenues.

As a technology centre, CANMET must satisfy three criteria. It must:

- a) Operate under the guidance of client-led advisory board to guide its various technology support activities.
- b) Publish an annual business plan.
- c) Encourage the highest possible financial contribution from industry and other clients consistent with the ability of users to pay for the services provided.

Conditions (a) and (b) above have been satisfied:

- The Minister's National Advisory Council to CANMET (MNACC) has been created and is fully operative in guiding CANMET's priorities.
- MNACC is divided into subcommittees for each of the laboratories.
- Technical advisory groups made up of CANMET and external personnel are set up to advise each research program.
- Since 1988, three-year business plans are published yearly.

As far as item (c) is concerned, CANMET has adopted shared funding as one of its objectives and has added other objectives in its mission statement. Quoting from the 1988-91 Business Plan:

"In partnership with its clients, CANMET performs and sponsors predominantly commercial and cost-shared research and development and technology transfer with the following mandate:

- to enhance the competitiveness of the Canadian mineral, metal and energy industries;
- to improve health, safety and environmental control in the client industries; and
- to support governmental policy initiatives."

In the following, we examine the extent to which the projects selected for review satisfied one or more of the three criteria listed or implied in the mission statement above:

- Leverage of R&D funding: the stimulation of private spending on R&D through public R&D funds.
- Enhancement of health, safety, and environmental controls in client industries.
- Support of the government's goal of balanced regional economic development.

B. OVERALL LEVERAGE OF PRIVATE R&D FUNDING HAS BEEN GOOD

Exhibit IX-1 compares the CANMET expenditures for the nine projects studied here to R&D expenditures by industry for these projects.

The data on net present value of program costs shown in this exhibit were extracted from the analysis contained in the preceding chapters. Data on expenditures by others were obtained from the program team and/or industry sources. In this table, we distinguish between the two types of expenditures by others:

- External contributions to cover some of CANMET's own project costs.
- Additional expenditures of organizations involved in the project.

The following explains the entries in the table:

1) Fossil fuel heating systems

The Marbek report on the Fossil Fuel Heating project indicates that 40% of the program costs were incurred by industry in the period 1971-78. After that date private contribution was not solicited to ensure that results would remain in the public domain. Program cost in 1987 dollars are shown in the Marbek report as \$3.9 million. Forty per cent of that cost amounts to \$1.9 million in 1990 dollars. With a total program cost of \$15.1 million (see paragraph B3 in chapter IV) the CANMET share was \$13.2 million (1990). The leverage ratio of 0.14 for the total program may not be a good representation

EXHIBIT IX-1 Leverage Summary

Project	R & D Expenditures - \$ Million (1990)			
	CANMET Share	Others		Leverage: \$ Others/ \$ CANMET
		Through CANMET	Additional	
<u>A. Energy research laboratories</u>				
- Fossil fuel heating systems	13.2	1.9	N/A	.14 (1971-78)
- Safety limits for coking pressure/ ² Use of Western Canadian coals	1.6	-	-	0
<u>B. Metals technology laboratories</u>				
- Pressure vessel fabrication	4.2	-	0.1	0.02
- H ₂ S cracking of line-pipe steels	2.1	2.1	-	1.0
<u>C. Mining research laboratories</u>				
- Canada-Ontario-Industry rockburst project	4.2	-	12.3	2.9
- Liesel exhaust cleaning technology	3.5	-	5.6	1.6
<u>D. Mineral science laboratories</u>				
- Bioleaching of uranium	2.5	-	2.8	1.1
- Supplementary cementing materials	8.2	-	1.0	0.1
<u>E. Coal research laboratories</u>				
- Monolithic packing technology	0.3	-	0.07	0.2
Total ¹	26.6	4.0	21.87	0.97

¹Excludes fossil fuel heating systems due to missing data.

²Excludes costs borne by domestic steel makers.

of the true leverage achieved. As indicated above, there was a conscious decision on CANMET's part after 1978 to fund 100% of the research to ensure full public disclosure of its results. Presumably, as industry started to take advantage of some of the research results, individual manufacturers must have conducted their own Research and Engineering work to adapt the CANMET results to their own particular product designs. It would not be practical to try and determine the level of effort involved in this activity. Given the commercial success of the developments fostered by this project, all we can say is that the private research and engineering effort surrounding commercialization of the project results must have been significant.

2) Safety limits for coking pressure/use of Western Canadian coals

The CANMET expenditures for this project were shown in Chapter IV to be \$3.2 million in 1990 dollars. A steel company did contribute a coke oven battery for this work. However, that battery was due to be scrapped and had zero book value. So, to be conservative, we assigned a zero value to this item. It could be argued that it had some implied residual value if it was used for research. On the other hand, the program team indicates that the research probably would not have been carried out had this equipment not been made available at zero cost. Clients involved in this project spent an additional \$1.8 million (1990) on manpower and other costs associated with the project. The ratio of external research dollars to CANMET dollars for this project is therefore 0.56. All the external contributions to this project were from steel producers.

The Western coal producers did not contribute. But Western Canadian coal mines are an industry in need of support and the CANMET contribution was certainly in line with Federal Government regional and social objectives.

Since we exclude the benefits and costs related to the impact to domestic steel makers, Exhibit IX-1 shows a contribution and leverage of zero. However, as noted earlier, if the contributions of steel companies were included the leverage ratio would be 0.56.

3) Pressure vessel fabrication

The Pressure vessel fabrication work was performed in two major projects: one initiated in 1982, the other initiated in 1985. Both projects were carried out under contract by Babcock and Wilcox. This contractor's staff indicate that the 1982 contract covered all their costs. But for the 1985 contract they incurred additional expenditures of \$70,000 at the start of the contract. Expressed in 1990 dollars, this expenditure amounts to \$100 thousand. These expenditures yield a rather low leverage ratio of 0.02.

4) H₂S cracking of line-pipe steel

Exhibit IV-3 showed that the program cost of the H₂S cracking of line-pipe steel project was \$4.1 million (1990). This program was 50% funded by CSA on behalf of the Canadian Petroleum Association; i.e., CSA's contribution is of the order of \$2.0 million (1990). In addition, two other organizations -- DSS and C&M -- contributed relatively small amounts: \$62 thousand and \$59 thousand respectively. The overall leverage ratio was therefore 1.0.

5) Canada-Ontario-Industry Rockburst Project

Exhibit VI-3 indicates that the CANMET expenditures on this project were \$3.4 million in current dollars and 4.2 million in 1990 dollars. The program team estimates expenditures by Ontario and industry at \$2.5 and \$7.5 million (current) respectively. Assuming approximately the same relationship between current and constant 1990 dollars for these expenditures as for CANMET, yields a constant 1990 dollar value of \$3.0 million for Ontario and \$9.2 million for industry. In this instance, CANMET was quite successful in inducing others to contribute to the research. These other groups contributed 2.9 times what CANMET contributed.

6) Diesel exhaust cleaning technology

Exhibit VI-6 showed that CANMET research costs for the Diesel exhaust cleaning technology project was \$3.4 million (1990). Agencies external to CANMET spent an additional \$3.1 million in current dollars. Assuming the same relationship between cumulative current dollar expenditures and constant 1990 dollars for these external agencies as for CANMET yields a 1990 present value of \$5.6 million (1990). The leverage ratio stood at a high value of 1.6.

7) Bioleaching of uranium

Section B4 (Summary) of Chapter VII explains that the CANMET costs for the bioleaching of uranium project had a present value of \$2.5 million (1990). The corresponding expenditures for Denison and NRC-IRAP is \$2.8 million for a leverage ratio of 1.1.

8) Supplementary cementing materials

The value of the level of effort expended on this project by CANMET personnel has been placed at \$8.2 million. It is estimated that approximately \$855,000 has been levered from private industry and other government organizations in the last 3 to 4 years. This represents approximately \$1 million in 1990 dollars. As a result, the leverage ratio is 0.1.

9) Monolithic packing technology

The CANMET level of effort in the Monolithic Packing Technology project was low compared to the other projects: \$300 thousand. The expenditure by the client CBCL, was only \$70 thousand for a leverage ratio of 0.2. However, one should take into account the depressed state of that area of Canada and as in the case of the Safety Limits/ Use of Western Canadian coal project this low leverage factor can be justified on the basis of social and regional objectives.

10) Overall results

For one project the full contribution by others could not be adequately assessed. If we consider the eight remaining projects and add up the total CANMET expenditures and total expenditures by others, we arrive at an overall leverage of 0.97. Therefore, on average CANMET was able to generate R&D expenditures by others equal to its own R&D expenditures. In addition, as was mentioned earlier in the case of the Fossil

Fuel Heating Systems projects, others may have been spurred on to conduct downstream research to apply the CANMET findings to their particular situation.

Exhibit IX-2 lists the leverage ratios and benefit/cost ratios for the projects selected for our analysis. There is a good deal of spread between the various numbers in this exhibit and there are too few projects to make definite statements about any possible relationship between benefit/cost ratio and leverage ratio.

C. THE SELECTED PROJECTS SHOW A GOOD FOCUS ON SAFETY, REGIONAL DEVELOPMENT AND ENVIRONMENTAL CONCERNS

Exhibit IX-3 relates, in a qualitative, way each of the projects under study to a potential impact on:

- Safety in the home, in the work place or during travel.
- A given Canadian region.
- Protection of the environment.

We see that all the projects under study satisfy at least one such criterion. Some satisfy all three. As far as regional focus is concerned, regions are shown to benefit either because one or more projects focused on that region or because some projects cover all regions.

Quebec and British Columbia do not appear specifically among the regions that are targeted by the CANMET research. On the other hand, a project such as Diesel Exhaust Cleaning Technology will benefit all mining regions in Canada which includes British Columbia and Quebec.

D. POLICIES FOR SELECTING FUTURE PROJECTS

CANMET has a mandate to:

- Enhance the competitiveness of the Canadian mineral, metal and energy industries.
- Improve health, safety and environmental control in the client industries.
- Support governmental policy initiatives.

This section deals with the selection of future projects with an economic rationale. It does not consider project selection issues where the principal benefit is a social one or where the project is in support of government policy.

EXHIBIT IX-2 Leverage Ratios and Benefit/Cost Ratios

Project	Leverage Ratio	Benefit/Cost Ratio ¹
A. <u>Energy research laboratories</u>		
- Fossil fuel heating systems	N/A	2.5
- Safety limits for coking pressure/ ² use of Western Canadian coals	0.0	2.6
B. <u>Metals technology laboratories</u>		
- Pressure vessel fabrication	0.02	0.6
- H ₂ S cracking of line-pipe steel	1.0	4.5
C. <u>Mining research laboratories</u>		
- Canada-Ontario-Industry rockburst project	2.9	14.8
- Diesel exhaust cleaning technology	1.6	4.2
D. <u>Mineral science laboratories</u>		
- Bioleaching of uranium	1.1	2.2
- Supplementary cementing materials	0.1	27.7
E. <u>Coal research laboratories</u>		
- Monolithic packing technology	0.2	1.8

¹This ratio is estimated as the total benefit divided by total costs of the project.

²Excludes cost and benefit impacts to domestic steel makers.

EXHIBIT IX-3 Social Impacts of Selected CANMET Projects

Project	Safety impact	Regional impact	Environmental impact
A. <u>Energy research laboratories</u>			
- Fossil fuel heating systems	-	All regions	Reduction in CO ₂ discharges
- Safety limits for coking pressure/ Use of Western Canadian coals	Enhanced safety in steel mills	Benefit to Western Canada	-
B. <u>Metals technology laboratories</u>	Project evolving toward service performance	-	-
- Pressure vessel fabrication			
- Sulphide stress cracking of line-pipe steels	Prevention of pipe-line leaks	Western Canada	Prevention of natural gas leaks to the atmosphere and seepage of hydro carbon liquids through the soil
C. <u>Mining research laboratories</u>			
- Canada-Ontario-Industry rockburst project	Enhanced safety in hard rock mines	Northern Ontario	-
- Diesel exhaust cleaning technology	Reduction of carcinogenic emissions	Mining regions of Canada	-
D. <u>Mineral science laboratories</u>			
- Bioleaching of uranium	-	Northern Ontario	-
- Supplementary cementing materials	Better concrete (silica fume)	All regions/ Northern Ontario plant	Disposal of mine/ power plant wastes
E. <u>Coal research laboratories</u>			
- Monolithic packing technology	Enhanced safety in coal mines	Cape Breton	-

Selecting R&D projects for funding out of a list of candidate projects is a complex task. A good deal of literature has been written on the subject and through the MNACC and TAG system, CANMET has evolved a management process to perform this difficult task.

Our analysis brings to the fore the issue of leverage ratio and its potential influence on the advisability of the research. In a perfect world, if a particular public or private organization is confronted with a problem, its willingness to spend dollars on a piece of research is dependent upon the expected value of the benefit, i.e. if the size of the benefit times the probability of the research being successful is greater than the cost of the research, one should go ahead with the research. The greater the statistical expectation of the net benefit, the greater the perceived degree of comfort or the lower the risk in undertaking the research. This process is carried on over a series of candidate projects until no research project with a net positive pay-off is left, or the research budget is expended.

In an imperfect world, however, the risk in the research (i.e. the probability that the research will not be successful) is itself a matter of conjecture, debate and opinion. Also, different organizations will accept different levels of risk for a variety of reasons (research orientation, propensity to risky investments, total resource level). An organization such as CANMET should step in with the minimal injection of research funding required for the project to go ahead. At one extreme, if the risk is minimal, those who will benefit from the research should undertake it themselves or in the case of society at large via the appropriate government or public advocacy group. If the research is in an area where CANMET has a specific mandate and expertise, then CANMET could do the research on behalf of the sponsoring group on a cost recovery contract basis.

At the other extreme, the potential beneficiary of the research or a representative organization is unwilling to spend any money toward the research effort. Should CANMET still go ahead on its own? The answer is probably no.

In the "in between" cases, CANMET has to canvas for partial sponsorship of projects, an activity its staff is increasingly involved in.

In a 1978 Rand Corporation study conducted for the U.S. Office of Technology Assessment "The Role of Demonstrations in Federal R&D Policy" the authors (T.K. Glennen et al) showed that a key factor in the success of demonstration projects was the identification of an "audience" and its eventual support and participation.

Transferring this result to CANMET and borrowing from the analytical philosophy of this report means that to support its initial marketing efforts and search for sponsors for a particular project CANMET should conduct a "potential socio-economic benefit study" to identify the beneficiaries of the research and size up their potential benefits. Such a study would also identify the risk that the research -- even if successful -- may not prove useful if a change were to occur in the economic scenario. This was the case for two projects examined in our Phase I report: CANMET hydrocracking and Development of plate steels for offshore structures and Arctic vessels. These projects were technically successful but did not yield economic benefits because the forecast demand did not materialize. As well, the Pressure Vessel Fabrication Technologies project we reviewed suffered from a change in economic circumstances. In that case, an *a priori* cost-benefit analysis was undertaken but did not correctly predict the contraction of the petro-chemical industry.

The willingness of an industry to sponsor a given research project is a barometer of this industry's confidence that if the R&D is successful, the socio-economic environment will still be favourable to its exploitation. An *a priori* benefit-cost analysis can be a useful tool in ranking the desirability of CANMET conducting research projects and enlisting partial or total external sponsorship. However, as noted in the case of Pressure Vessel Fabrication Technologies, the cost-benefit analysis may not be able to predict all eventualities.

X

SUMMARY AND CONCLUSIONS

A. INTRODUCTION

This chapter summarizes our findings on the review of selected CANMET Research and Development projects. Further it highlights the significance of the projects in the context of prevailing R&D policies of the Federal government.

B. PROJECT FINDINGS

We reviewed nine CANMET projects in terms of their social costs and benefits. Results are noted in Exhibit X-1. As the exhibit illustrates, eight of the projects resulted in a positive net present value. The value of the benefits of these projects exceeded the value of the project costs. In our opinion, the remaining project would have resulted in a positive net present value except for the:

- Unanticipated decline in the domestic petro-chemical industry.
- Uncompetitiveness of the domestic fabricators in large vessel fabrications.
- Limited use of the technologies in other fabrications.

In one project (Safety Limits for Coking Pressure/Use of Western Canadian Coals), we have been forced to quantify only one portion of the project -- that benefitting Western Canadian coal producers -- when we could not obtain agreement on the incremental impact to domestic steel makers in our validation exercise. This project has the potential to add significantly to the benefits noted in Exhibit X-1.

Projects for review were selected based on the size of their expected benefits. As a result, the net present value of the reviewed projects should not be viewed as typical of all CANMET projects. Other projects may offer high benefits. However, not all projects are likely to generate positive net present values. This is the nature of research. In fact, the negative net present value for one project, thought to offer potential benefits, is an example of what can go wrong even with a technically successful project.

We reduced the benefits of one project (Bioremediation of Uranium) through our validation exercise when a downturn in the market for the output of the process reduced the expected use of the technology. This is again an example of what can go wrong with a technically successful project.

EXHIBIT X-1 Findings of Review of Selected CANMET Research and Development Projects

Project	Person-Years	CANMET Costs	Net Present Value (NPV)	Internal Rate of Return (IRR)
	(#)	(million \$)	(million \$)	(%)
Fossil fuel heating systems	66.0	15.1	23.2	NA
Safety limits for coking pressure/use of Western Canadian Coals ¹	9.0	1.6	2.6	25
Pressure vessel fabrication technologies	14.0	4.2	(1.5)	(1)
H ₂ S cracking of line-pipe steels	24.0	4.1	14.5	17
Canada-Ontario-Industry rockburst	31.5	4.2	229.0	104
Diesel exhaust cleaning technology	13.8	3.5	22.3	20
Bioleaching of uranium	5.4	2.5	6.4	9
Supplementary cementing materials	42.0	8.2	245.8	48
Monolithic packing technology	<u>1.9</u>	<u>0.3</u>	<u>1.4</u>	25
TOTAL ALL PROJECTS	207.6	43.7	543.7	
TOTAL PROJECTS WITH NPV > 0	193.6	39.5	545.2	

¹Excludes person-years, costs and benefits related to domestic steel makers.

As Exhibit X-1 illustrates the nine projects represent the effort of 208 person years of CANMET staff. This is equivalent to 28% of the current staff allocated to CANMET.¹

Costs of the CANMET projects are \$43.7 million, \$39.5 million if the eight projects with positive net present values are considered. These costs represent 55% (50% excluding Pressure Vessel Fabrication Technologies) of the annual budget for CANMET.

¹In this section we use the fiscal year 1990/91 Resource Allocations for CANMET to compare to project findings. We deduct Branches recently added to CANMET (Efficiency & Alternative Energy Technology Branch and Administration of Canada Explosives Act). The CANMET allocations are 732 person years and a budget of \$79.4 million. This budget includes salaries, capital equipment and contract funds. It does not include any allocation for buildings but includes overheads such as the Director General's offices and the Policy, Planning & Services Branch.

The projects have produced benefits exceeding all private and public sector (including CANMET) costs by \$543.7 million (\$545.2 million excluding Pressure Vessel Fabrication Technologies). At current resource levels these project net benefits represent 6.8 years of CANMET activity. Thus, the projects reviewed in our study have contributed benefits to society equivalent to approximately seven years of CANMET operations.

We reviewed only nine projects intensively. These projects were found to provide benefits that not only covered the costs of the projects but also produced excess benefits equivalent to seven years of CANMET activities. This calculation does not include the contribution by other CANMET projects. As a result, these are implicitly valued at zero. However, other projects will generate benefits for society which exceed the social costs of the projects. As a result, the figure of seven years is a lower bound estimate of the contribution of CANMET projects.

In Exhibit X-1, two projects account for almost 90% of the calculated net present value. This may be a characteristic of research and development activities. Some projects produce benefits exceeding costs while only a few result in substantial net benefits.

The internal rate of return (IRR) for the projects shows a similar result. This rate, which produces a net present value equal to zero, ranges from a low of minus 1% to a high of 104%. This diversity in rates of return is in keeping with a comprehensive study of 17 innovations in the United States by Mansfield *et. al.*¹ wherein the authors estimate social rates of return ranging from negative values to in excess of 300%.

C. RESEARCH AND DEVELOPMENT POLICY ISSUES

The nine CANMET projects we reviewed levered \$0.97 for every \$1.00 expended by CANMET. Although our sample is small this demonstrated willingness by those outside of CANMET to participate in the funding of the project may provide an a priori measure of the probable benefit to be derived from the project.

We found that the reviewed projects also demonstrated a good focus on safety, regional development and environmental concerns.

As a result, we conclude that the projects illustrate contribution toward the listed or implied goals of CANMET's mission statement:

- Leverage of R&D funding : the stimulation of private spending on R&D through public R&D funds.
- Enhancement of health, safety, and environmental controls in client industries.
- Support of the government's goal of balanced regional economic development.

¹Mansfield, Edwin and John Rapoport, Anthony Romeo, Edmond Villarri, Samuel Wagener, Frank Husic *The Production and Application of New Industrial Technology*, (Norton, New York: 1977).